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ESTABLISHMENT CRITERIA FOR CATEGORY I INSTRUMENT LANDING SYSTEM (ILS)

DECEMBER 1975

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16 Abstract

This report develops revised establishment criteria for the Instrument Landing System (ILS) with approach lights based on benefit/cost analysis, as follows:

1. Air carrier airports with sustained turbojet operations are eligible for an initial ILS (same as previous criteria).

2. At other than jet-use carrier airports and for multiple ILS installations, criteria are expressed as a function of (a) annual instrument approaches by user category, and (b) nonprecision approach minimums on the candidate ILS runway. For example, a runway at a nonhub air carrier airport without turbojet service that has nonprecision approach minimums of 500-1 is an ILS candidate with any combination of 350 air carrier, 375 air taxi, or 1,500 general aviation annual instrument approaches.

The primary impacts of the revised criteria are to lower ILS establishment levels at air carrier airports and to raise them at general aviation airports. It is estimated that in the short term 81 additional air carrier runways and one addition general aviation runway would meet the revised numeric (but not necessarily other) criteria. Over the next 10 years, potential candidates under the revised criteria are about 95 percent of those under the previous criteria.

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EXECUTIVE SUMMARY

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3. Criteria for installing ILS at remote locations, for training, and for noise abatement have been retained.

The primary impacts of the revised criteria are to lower ILS establishment levels at air carrier airports and to raise them at general aviation airports. It is estimated that in the short term 81 additional air carrier runways and 1 additional general aviation runway would meet the revised numeric (but not necessarily other) criteria. Over the next 10 years, potential candidates under the revised criteria are about 95 percent of those under the previous criteria.

Benefits of an ILS vary widely, depending on the proportionate use of the ILS runway, the distribution of instrument weather at the airport, aircraft operating costs and average number of passengers, and other factors. Therefore, ILS candidates identified by means of establishment criteria will be screened in FAA Headquarters, using supporting data furnished by the regions with their responses to the annual Call for Estimates.

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SECTION I - INTRODUCTION AND PURPOSE

Criteria for the establishment of terminal air navigation facilities and air traffic control services provided by the FAA are published in Airway Planning Standard Number One (APS-1) (Reference 1). These criteria are published to foster the planned development of a safe and efficient National Airspace System while at the same time guiding the allocation of resources for facilities and services.

The purpose of this report is to develop revised establishment criteria for the Category I Instrument Larding System (ILS). The new criteria are based on an analysis of the costs and benefits of ILS's and expressed in terms of annual instrument approaches (AIA) on the candidate runway.

According to APS-1, an airport is a candidate for the establishment of a facility or service when it meets the specified criteria and it is economically justified by a benefit/cost analysis. Recognizing the burden that would be placed on field facilities by requiring detailed benefit/cost analyses of potential candidates and their objections to such a procedure, ILS establishment criteria based on typical or normalized costs will be used by regional personnel to identify potential ILS candidates during preliminary budget formulation. Candidates thus identified will be screened and ranked by benefit/cost analysis in FAA Headquarters, using supporting data furnished by the regions with their responses to the annual Call for Estimates. Regional offices will have the option of using benefit/cost analysis to identify potential ILS candidates.

SECTION II - PREVIOUS ILS ESTABLISHMENT CRITERIA

Previous criteria for Category I ILS/MALSR, as published in APS-1, were:

1. Initial ILS

    a. Scheduled air carrier turbojet operations or

    b. 700 or more annual instrument approaches

2. Multiple ILS - airport total of 3,000 or more annual instrument approaches and 700 or more annual instrument approaches to each candidate ILS runway.

Provision also is made for installing ILS at remote locations, for training, and for noise abatement. A number of other requirements such as adequate runway length and runway edge lighting must be met to qualify for an ILS, but these are not pertinent here.

SECTION III - REVISED ESTABLISHMENT CRITERIA
FOR CATEGORY I ILS

The benefits provided by a Category I ILS depend on a number
of factors--the reduction in minimums the ILS gives, the
relative amount of Category I weather at the airport, IFR
flight activity at the airport and on the ILS runway, types
of aircraft and numbers of passengers using the airport, and
other factors. Two of the most important of these are the
prospective users of the ILS and the reduction in minimums
that the ILS will give. User category is important because
ILS benefits are proportional to aircraft operating costs and
numbers of enplaned passengers. The reduction in minimums
determines the increase in runway utilization during instru-
ment weather conditions with the ILS. For these reasons,
user category and existing nonprecision approach minimums of
the candidate ILS runway are included explicitly as variables
in the "activity" establishment criteria. Revised establish-
ment and discontinuance criteria for Category I ILS are:

1. Establishment

   An airport where scheduled air carrier turbojet opera-
   tions are conducted on a sustained basis, or any other
   airport which meets the annual instrument approach cri-
   teria in paragraph 2, is a candidate for Category I ILS
   with an approach light system. (Provisions that are not
   relevant to this discussion have been omitted, e.g., the
   operation must be safe, runway lights are required, etc.)

2. Annual Instrument Approach Criteria

   An airport is a candidate for an initial or a multiple
   ILS with approach lights when the annual instrument
   approaches recorded for the runway on which the ILS is
   to be installed meet or exceed any combination of the
   conditions shown in Table 1.

3. Benefit/Cost Screening

   ILS candidates identified by the procedures in Table 1
   will be screened in FAA Headquarters using the benefit/
   cost technique described in this report. FAA regional
   offices shall submit data required for screening purposes
   with their responses to the annual Call for Estimates.
   This provision does not apply to airports that qualify
   for an initial ILS under the air carrier turbojet service
   criterion.

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TABLE 1

Annual Instrument Approach Criteria

User Category	Nonprecision Approach Minimums on the Candidate ILS Runway					
	300-3/4	400-3/4	400-1	500-1	600-1	700-1
Air Carrier						
Large Hub	300	200	150	100	75	50
Medium Hub	400	250	200	150	100	75
Small Hub	500	300	250	175	125	100
Nonhub	1,000	600	500	350	250	200
Air Taxi	750	550	475	375	300	225
General Aviation	2,500	2,000	1.800	1,500	1,200	900

NOTE: These AIA levels apply only when the ILS will give minimums of 200-$\frac{1}{2}$ or the equivalent; if lesser minimums are achievable, consult with the Office of Aviation System Plans to determine procedures (criteria) that are applicable.

To determine whether an airport meets Annual Instrument Approach (AIA) criteria·

o Determine the least approach minimums currently authorized for the largest aircraft using the candidate runway, e.g., 500-1.

o Reference the above table to select the qualifying numbers of AIA's on the candidate runway for each user category, e.g., small hub - 175, air taxi - 375, general aviation - 1500.*

o Compute the number of recorded AIA's on the candidate runway for each user category as follows:

  1. Determine the AIA's by an on-site survey; or

  2. Calculate the AIA's by estimating the percentage of the total airport AIA's that used the candidate runway. Multiply this percentage by the total airport AIA's to determine the recorded AIA's.

o Enter recorded and qualifying AIA's for the candidate runway as indicated below. The contribution of each category toward meeting the criteria is determined by summation. A runway with a total ratio of 1.0 or more meets the AIA criteria.

<u>User Category</u>

Air Carrier: $\frac{\text{Recorded AIA's}}{\text{Qualifying AIA's}}$ =   x.xx

Air Taxi· $\frac{\text{Recorded AIA's}}{\text{Qualifying AIA's}}$ =   x.xx

General Aviation: $\frac{\text{Recorded AIA's}}{\text{Qualifying AIA's}}$ =   x.xx

  Total Ratio   x.xx

*Hub designation is determined by enplanements at candidate airports.

4. Discontinuance

a. At an airport where scheduled air carrier turbojets operate the ILS shall not be decommissioned. At an airport where air carrier turbojet operations are discontinued and are not forecast to be resumed, the discontinuance criteria in 4(b) shall apply.

b. Airports having no scheduled air carrier turbojet operations are candidates for decommissioning of an ILS when the instrument approach activity falls to two-thirds* of the qualifying level. The decommissioning of an ILS shall be justified by a benefit/cost study.

Provisions for installing ILS at remote locations, for training, and for noise abatement have been retained.

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*Annual O&M costs are about two-thirds of prorated investment costs.

SECTION IV - TYPICAL CATEGORY I ILS COSTS

A standard Category I ILS consists of a localizer and a
glide slope, outer and middle marker beacons, and a 2,400-
foot MALSR (Medium Intensity Approach Light System with
Runway Alignment Indicator Lights). Distance measuring
equipment (DME) may be used instead of marker beacons if the
approach is over water or for some other reason the siting
of the markers is impractical. A compass locator often is
situated at the outer marker site, but it is not part of the
ILS. A Category I ILS usually will give landing minimums of
200-foot decision height and one-half mile visibility (or
Runway Visual Range 2400). Runway Visual Range (RVR) 1800
can be achieved with operative touchdown zone and runway
centerline lights.

ILS/MALSR costs include the costs of the equipment and its
installation, annual operation and maintenance, and flight
inspection. ILS's also may require considerable grading to
prepare the site and the removal of obstructions. Although
these items are paid for by the airport sponsor, in most
cases with ADAP assistance, they are required and have been
included in the cost package. U. S. aircraft generally are
well equipped to use the ILS so avionics costs have been dis-
regarded in this report. Typical FY 1975 costs of major
ground system components are summarized below:

Cost Item	ILS	MALSR	Total
Investment (000)			
Establishment	$219	$80	$299
Site Preparation	100	--	100
Total	$319	$80	$399
Annual O&M (000)			
Maintenance	$ 23	$ 7	$ 30
Stocks and Stores	9	1	10
Flight Inspection	9	--	9
Total	$ 41	$ 8	$ 49

The $219,000 ILS establishment cost is for a turnkey instal-
lation and may exclude some power line, monitor line, and
related costs. ILS site preparation costs vary widely, from
a few thousand dollars to more than a million dollars for

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unusually difficult sites. The "typical" site preparation cost shown on the preceding page was developed by Crosswell (Reference 2). Some items required for instrument approach capability have been omitted from the tabulation because the airport sponsor ordinarily would provide them in any case, e.g., adequate runway length, runway edge lighting, and rotating beam ceilometer.

SECTION V - ECONOMIC BENEFITS OF ILS

The primary quantifiable benefits of ILS are safety and efficiency. The precise lateral and vertical guidance an ILS gives reduces risk during approach and landing, particularly during instrument weather conditions. The decrease in flight disruptions (delays, diversions, and cancellations) associated with reduced landing minimums leads to a more efficient operation. Installation of an ILS also is believed to stimulate the demand for air transportation through greater reliability of service, contribute to the economic development of the community, and provide other but difficult-to-measure benefits; however, these latter benefits are not discussed in this report.

Costs of Flight Disruptions

Weather-caused flight disruptions--delays, diversions, and cancellations--impose economic penalties on both aircraft operators and passengers. Delays and diversions increase aircraft operating costs. Cancellations result in loss of revenue. All three types of disruptions create extra passenger handling expense (reticketing, meals, and overnight accommodations in some cases or providing alternate means of transportation.

Weather conditions of the kind that prevail when an airport is closed often persist for several hours, so that when delays are encountered they tend to be rather lengthy. Furthermore, delays beget delays. Temporarily closing one airport often leads to delays at subsequent stops along a route. The diversion of an aircraft from its intended destination may cause the cancellation of the following flight.

Most of the costs of flight disruptions are borne by the passengers, who suffer both delay and inconvenience. Since airports vary widely with respect to the numbers of passengers they handle, average number of enplaned passengers is a variable in the flight disruption cost estimating equations that have been developed.

Average flight disruption costs are developed in Appendix A and summarized on page 10 (A schematic illustration of the determination and application of these costs is shown in Figure 1).

CALCULATED UNIVERSAL DATA

AVG. DELAY TIME

VALUE OF PASS TIME

ACFT OPNG COST

INFO FOR INDIVIDUAL AIRPORT

NO. PASSENGERS

COST OF AVG DISRUPTION

AIRPORT AIA'S

LOCAL WX

% RWY USE

RUNWAY DISRUPTIONS

$ SAVED DUE TO DISRUPTIONS AVERTED

DISRUPTIONS AVERTED ON RUNWAY

PRESENT MINIMUMS

NEW MINIMUMS

% ACFT EQUIPPED

RUNWAY AUGMENTATION
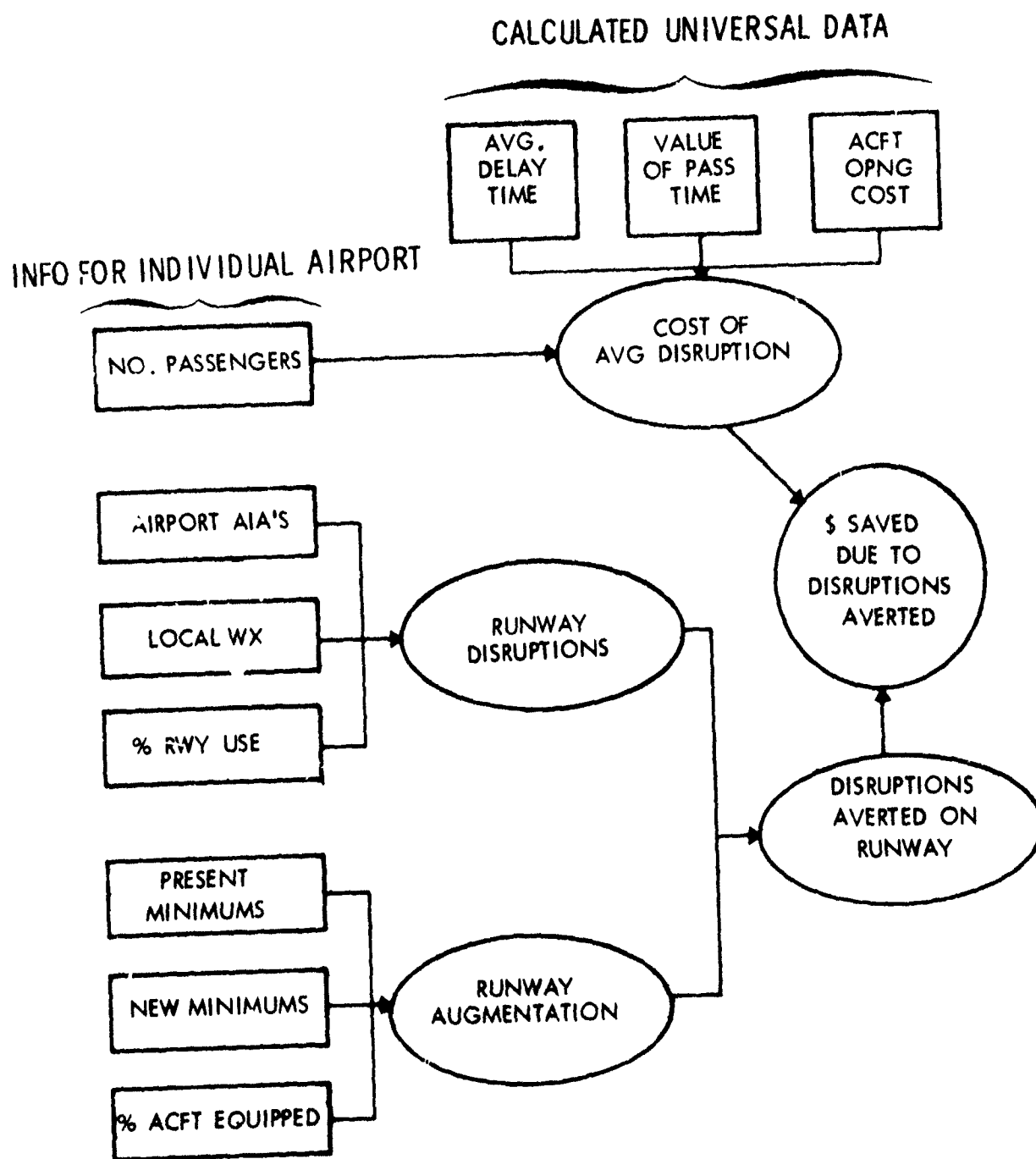
FIGURE 1. -- SCHEMATIC DETERMINATION OF COSTS OF FLIGHT DISRUPTIONS

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Air Carrier

Hub Airport	$48n + $293
Nonhub Airport	97n + 60

Air Taxi   50n + 9

General Aviation   15n + 12

where n is the number of deplaning
passengers

These equations were developed by estimating aircraft and
passenger delay times associated with various types of flight
disruptions and assigning costs to these delays. Average
flight disruption costs were obtained by weighting each kind
of disruption--delay, diversion, and cancellation--by its
relative frequency of occurrence.

Passenger time lost, including primary plus secondary effects,
was estimated to vary from 3/4 hour for a delayed general
aviation aircraft to 7 1/2 hours for the diversion of an air
carrier aircraft to an alternate airport and cancellation of
the next flight. A value of $12.50 an hour was estimated for
passenger time lost. Other costs entering into the equations
(aircraft operating costs, extra passenger handling expenses,
and revenue losses from flight cancellations) are detailed in
Appendix A.

Numbers of passengers is a variable in each of the flight dis-
ruption cost estimating equations given above. For broad
planning purposes, we can estimate the average number of pas-
sengers deplaning each type of flight and convert the cost
equations above to average dollar values, as follows:

Type of Flight	Average Number of Deplaning Passengers*	Average Cost per Flight Disruption
Air Carrier		
Large Hub	54.0	$2,885
Medium Hub	38.1	2,120
Small Hub	29.7	1,720
Nonhub	8.1	845
Air Taxi	6.3	325
General Aviation	5.0	90

*Average number of deplaning air carrier passengers derived from CAB/FAA Airport Activity Statistics (Reference 3); air taxi passengers from CAB Commuter Air Carrier Traffic Statistics (Reference 4); passengers, including crew, aboard general aviation IFR flights estimated from itinerant flight survey data.

Safety Benefits

Benefits of risk reduction include the prevention of two kinds of accidents--nonprecision approach accidents during IFR conditions and VFR landing and runway accidents. Of these, the IFR approach accidents are by far the most costly, especially in numbers of aviation fatalities.

ILS safety benefits are derived in Appendix B. These benefits are based on a recently completed MITRE report (Reference 12) which identified approach and landing accidents that might have been avoided if precision approach facilities had been available and used. During the 9-year period 1964 through 1972, there were 81 possibly avoidable nonprecision approach accidents in this country which resulted in 170 fatalities:

User Category	Accidents	Fatalities
Air Carrier	6	48
Air Taxi	20	43
General Aviation	55	79
Total	81	170

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Estimates of the safety benefits provided by an ILS through the prevention of nonprecision approach accidents were developed by converting numbers of accidents into accident rates and then dividing accident costs by the average number of approaches between accidents. This procedure gives a measure of the safety benefit per IFR approach provided by a precision approach aid.

Accident costs include loss or damage to property and loss or injury to human life. Aircraft replacement costs average about $6,000,000 for air carrier aircraft, $200,000 for air taxi aircraft, and $50,000 for general aviation aircraft. As nonprecision approach accidents often result in total destruction of the aircraft, it was estimated that loss or damage to aircraft averages 90 percent of replacement cost in these instances. Aircraft accident fatalities were costed at $300,000 each, a value based on non-Warsaw payment data furnished by the Civil Aeronautics Board.

During the same period, 1964-1972 small general aviation aircraft had 1,987 VFR approach accidents, with 191 fatalities, that might have been prevented with some sort of vertical guidance (ILS or VASI) and 6,684 runway accidents. The "risk cost" of these accidents was estimated to be about $0.50 per landing. About one-fourth of the general aviation fleet is equipped with glide slope. If pilots of these aircraft use the glide slope while making VFR approaches, the average benefit of an ILS for the prevention of VFR landing accidents is about 12 cents per itinerant landing. After making this adjustment and proportioning itinerant landings to instrument approaches, general aviation safety benefits were combined to represent the safety benefits per instrument approach.

Total safety benefits per instrument approach are tabulated below by user category and type of landing:

| | Benefit per IFR Approach of Preventable | | Total Safety |
User Category	IFR Approach Accidents	VFR Landing Accidents	Benefits per IFR Approach
Air Carrier			
Large Hub	$33	$*	$33
Medium Hub	25	*	25
Small Hub	20	*	20
Nonhub	10	*	10
Air Taxi	49	*	49
General Aviation	17	3	20

*Estimated to amount to one percent or less of the benefits of preventable IFR approach accidents.

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Full benefit credit has been given for potentially preventable accidents despite the fact that some of these accidents might have occurred even if better guidance information had been available (precision approach accidents are less frequent and less serious, on the average, than nonprecision approach accidents, but they occur). This was done for two reasons. First, the benefit analysis has been limited to those accidents that have been judged as being possibly avoidable had better approach and landing aids been available.

The second and perhaps more important reason is a risk avoidance argument. There is evidence that Congress and the public are risk avoiders with respect to aviation safety, that in their eyes safety benefits weigh more heavily than economic benefits. Investments in landing aids are a form of insurance against potentially disastrous accidents and, as such, conform both to public sentiment and to FAA policy, which places safety above all other considerations.

This reasoning also pertains to the present Airway Planning Standard criterion which states that "An airport where scheduled air carrier turbojet operations are conducted on a sustained basis...is a candidate for a Category I ILS with an approach light system..." Proper alignment on approach is especially critical with large turbojet aircraft because of their size, speed, and relatively slow response times. The National Transportation Safety Board has recommended that vertical guidance be provided on all runways serving air carrier jet aircraft. For these reasons, and because of the high costs of air carrier accidents, the air carrier jet-use criterion for ILS has been retained.

SECTION VI - DERIVATION OF ILS ESTABLISHMENT CRITERIA

Safety and efficiency benefits have been combined and related to the benefits associated with an averted flight disruption for use in developing the numeric ILS criteria. Safety benefits apply to all instrument approaches, not only the additional approaches that the ILS permits. They vary, therefore, with the reduction in minimums that an ILS will give. Take, for example, a runway at which 100 nonprecision approaches were recorded last year. If the installation of an ILS will permit an additional 10 AIA's, efficiency benefits will accrue to the 10 additional flight completions but safety benefits will be realized by all 110 IFR approaches; the ratio of flights receiving safety vs. efficiency benefits thus is 11-to-1. If, on the other hand, the ILS permits an additional 50 AIA's, the ratio of flights receiving safety vs. efficiency benefits is 150-to-50, or 3-to-1.

Average increases in runway utilization during instrument approach weather conditions associated with reductions from nonprecision approach minimums to ILS minimums (200-½) are developed in Appendix C* and tabulated below:

Nonprecision Approach Minimums	Average Increase in Airport Utilization with ILS Minimums of 200-1/2
300-3/4	5.7%
400-3/4	11.3%
400-1	15.0%
500-1	22.4%
600-1	31.7%
700-1	44.9%

To compute the safety benefits associated with an averted flight disruption, multiply the benefit per IFR approach by a safety improvement factor which is the reciprocal of the reduction in minimums plus one. For example, a reduction in

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*The more detailed data in Appendix C can be used to develop criteria for most combinations of nonprecision and precision approach minimums.

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minimums of from 400-1 to 200-½ will give an average increase
of 15 percent in runway utilization. The safety improvement
factor (F) in this case is:

$$F = 1/0.15 + 1$$

$$= 1.15/0.15$$

$$= 7.[7]$$

These computations have been carried out for a range of non-
precision approach minimums and are shown by user category
in Table 2. The efficiency benefit attributed to an averted
flight disruption is constant, of course, regardless of the
improvement in minimums the ILS gives. Safety benefits asso-
ciated with an averted flight disruption are inversely pro-
portional to the reduction in minimums--the smaller the
reduction the greater the number of instrument approaches that
will benefit per averted flight disruption from the safety
provided by the ILS.

The computations in Table 2 assume that an ILS will give
minimums of 200-½, regardless of the current nonprecision
minimums up to a maximum of 700-1. This is not always the
case, of course, although in many circumstances it will be.
An airport with circling minimums off a VORTAC located
20 miles away usually will have nonapproach minimums approxi-
mating 700-1; unless there are obstructions near the airport,
there is no obvious reason why the ILS shouldn't give mini-
mums of 200-½ in this typical case. To cite another example,
the VOR minimums for John F. Kennedy International Airport's
Category II runway are 600-1 for Categories A and B (small)
aircraft, 600-1½ for Category C aircraft, and 600-2 for
Category D (large jet) aircraft; La Guardia Airport's Cate-
gory II runway has even more restrictive VOR minimums.
Charlottesville-Albemarle Airport's Runway 3 has ILS minimums
of 200-½ and NDB minimums of 800-1 for Category C aircraft.
The "200-½" assumption underlying Table 2, in other words,
does not seem unreasonable.

On the other hand, there are many runways where minimums of
200-½ cannot be achieved with an ILS; in these instances the
numeric criteria developed from Table 2 would not apply.
Alternate criteria can be developed for these special cases
and, of course, the impact of the less-than-optimum minimum
reductions would show up during the benefit/cost screening.

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TABLE 2

ILS Safety and Efficiency Benefits Combined and
Related to the Benefits of an Averted Flight Disruption

User Group and Benefit Category	Current Nonprecision Approach Minimums					
	300-3/4	400-3/4	400-1	500-1	600-1	76'-1
Air Carrier						
Large Hub						
Safety Benefits	$ 610	$ 325	$ 255	$ 180	$ 135	$ 105
Efficiency Benefits	2,885	2,885	2,885	2,885	2,885	2,885
Total	$3,495	$3,210	$3,140	$3,065	$3,020	$2,990
Medium Hub						
Safety Benefits	$ 465	$ 245	$ 190	$ 135	$ 105	$ 80
Efficiency Benefits	2,120	2,120	2,120	2,120	2,120	2,120
Total	$2,585	$2,361	$2,310	$2,255	$2,225	$2,200
Small Hub						
Safety Benefits	$ 370	$ 195	$ 155	$ 110	$ 85	$ 65
Efficiency Benefits	1,720	1,720	1,720	1,720	1,720	1,720
Total	$2,090	$1,915	$1,875	$1,830	$1,805	$1,785
Nonhub						
Safety Benefits	$ 185	$ 100	$ 75	$ 55	$ 40	$ 30
Efficiency Benefits	845	845	845	845	845	845
Total	$1,030	$ 945	$ 920	$ 900	$ 885	$ 875
Air Taxi						
Safety Benefits	$ 900	$ 475	$ 375	$ 275	$ 200	$ 150
Efficiency Benefits	325	325	325	325	325	325
Total	$1,225	$ 845	$ 700	$ 600	$ 525	$ 475
General Aviation						
Safety Benefits	$ 370	$ 200	$ 150	$ 110	$ 85	$ 65
Efficiency Benefits	90	90	90	90	90	90
Total	$ 460	$ 290	$ 240	$ 200	$ 175	$ 155

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Discounted Costs and Benefits

The Office of Management and Budget has prescribed a standard 10 percent discount rate to be used in evaluating the measurable costs and/or benefits of programs or projects when they are distributed over time (Circular No. A-94, Revised). Over 15 years, the discount factor is 7.605. This factor was used to discount ILS operations and maintenance (O&M) costs.

ILS benefits are a function of traffic activity. Since air traffic is expected to increase throughout the next 15 years, net discount factors have been developed in Table 3 by multiplying OMB's discount factors by FAA's median forecast factors for 1975-1986 (Reference 9, extrapolated to 1990). These net discount factors, summed over the next 15 years, are: air carrier - 9.141; air taxi - 15.346; general aviation - 12.123.

Discounted lifetime ILS costs thus become:

Cost Item	Cost (000)	Discount Factor	Discounted 15-Year Costs (000)
Investment	$399	1.000	$399
Annual O&M	49	7.605	373
Total			$772

The 15-year streams of discounted benefits per averted flight disruption, by user group, were obtained by multiplying the values of Table 2 by the appropriate net discount factors. The results of these computations are given in Table 4.

TABLE 3

Discount Factors

Year After Funding	10% Discount Factor	IFR Growth Factors 1975-1990			Net Discount Factors for Benefits*		
		AC	AT	GA	AC	AT	GA
1	.909	1.035	1.120	1.067	0.941	1.018	0.970
2	.826	1.071	1.254	1.140	.885	1.036	.942
3	.751	1.109	1.404	1.216	.833	1.054	.913
4	.683	1.148	1.574	1.299	.784	1.075	.887
5	.621	1.188	1.762	1.386	.738	1.094	.861
6	.564	1.229	1.974	1.480	.693	1.113	.835
7	.513	1.247	2.122	1.591	.640	1.089	.816
8	.467	1.266	2.281	1.710	.591	1.065	.799
9	.424	1.285	2.452	1.839	.545	1.040	.780
10	.386	1.304	2.636	1.976	.503	1.017	.763
11	.350	1.324	2.834	2.125	.463	.992	.744
12	.319	1.344	3.046	2.284	.429	.972	.729
13	.290	1.364	3.275	2.455	.396	.950	.712
14	.263	1.384	3.521	2.640	.364	.926	.694
15	.239	1.405	3.785	2.838	.336	.905	.678
	7.605				9.141	15.346	12.123

*10% discount factor multiplied by IFR growth factor.

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TABLE 4

Discounted 15-Year Benefits Associated
with an Averted Flight Disruption
(in thousands of dollars)

User Category	Current Nonprecision Approach Minimums					
	300-3/4	400-3/4	400-1	500-1	600-1	700-1
Air Carrier						
Large Hub	$31.2	$29.3	$28.7	$28.0	$27.6	$27.3
Medium Hub	23.6	21.6	21.1	20.6	20.3	20.1
Small Hub	19.1	17.5	17.1	16.7	16.5	16.3
Nonhub	9.4	8.6	8.4	8.2	8.1	8.0
Air Taxi	18.8	12.3	10.7	9.2	8.1	7.3
General Aviation	5.6	3.5	2.9	2.4	2.1	1.9

SECTION VII - APPLICATION OF ILS AND BENEFIT/COST CRITERIA

This section illustrates by means of worksheets the application of the ILS criteria and of the benefit/cost criteria. The two applications are similar except that the benefit/cost criteria are more detailed.

The worksheet on the next page shows how a regional office might determine whether a runway was a candidate for an ILS. It also lists the information to be supplied for each ILS candidate submitted in response to the annual Call for Estimates. All of the required data should be readily available from or easily estimated by the airport operator or the local tower chief. Filling out the form takes only a few minutes.

The second worksheet illustrates the application of the benefit/cost procedure. Airports differ with respect to the average numbers of passengers per flight, and local weather patterns are quite variable. To take account of these differences, candidate ILS locations identified by means of the establishment criteria will be screened in FAA Headquarters by benefit/cost analysis.

In the example shown in the worksheets, Runway 21 at Joe Foss Field in Sioux Falls, North Dakota, the establishment criteria gave a ratio of recorded-to-qualifying AIA's of 2.2. The benefit/cost ratio was somewhat lower, 1.7. This happened because the number of enplaning air carrier passengers at Joe Foss Field is less, on the average, than that at most small hub airports. (It often happens that arriving flights carry through passengers, in which case the number of persons aboard aircraft and benefiting from the ILS will, on the average, exceed the average number of enplaning passengers. In these cases, the regions should estimate the actual number of passengers on board for use in the benefit/cost analysis.)

The benefit/cost worksheet will not be used in actual practice; the procedure has been computerized. However, it does show the steps in the procedure, which may be of interest to some readers. These are:

1. Determine the old and new approach minimums. An ILS, for example, might lower minimums for a runway from 400-1 to 200-½. Requires regional input.

2. From weather records, determine the percentage increase in runway utilization during IFR weather conditions that

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WORKSHEET FOR APPLICATION OF ILS CRITERIA

Location: _Sioux Falls, S. D._   Runway _21_

Airport: _Joe Foss Field_   Hub Type _Small_

IFR Minimums: Nonprecision _400-3/4_   ILS _200-1/2_

Estimated IFR Use of Candidate Runway _30%_

AIA's on Candidate ILS Runway (FY-1974):

	1974 AIA's	Runway Use Factor	AIA's on Candidate Rwy
Air Carrier	2,032	.30	610
Air Taxi	89	.30	27
General Aviation/Military	1,089	.30	327

Proportion of Criteria Satisfied:

	Recorded AIA's	Qualifying AIA's	Ratio
Air Carrier	610	300	2.03
Air Taxi	27	550	.05
General Aviation/Military	327	2,000	.16
Total			2.24

Data to be Furnished by Region:

Estimated ILS Minimums _200-1/2_

Estimated IFR Use of Candidate Runway _30%_

Average Number of Passengers

Air Carrier _18.3_

Air Taxi _6.3_

General Aviation _5.0_

WORKSHEET FOR APPLICATION OF BENEFIT/COST ANALYSIS

Location _____ *Sioux Falls, S. D.* _____ Runway _____ *21* _____

Airport _____ *Joe Foss Field* _____ Hub Type _____ *Small* _____

IFR Minimums Nonprecision _____ *400-3/4* _____ ILS _____ *200-1/2* _____

Increase in Candidate Runway Use with ILS _____ *11.3%* _____

Estimated IFR Use of Candidate Runway _____ *30%* _____

ILS-equipped IFR Aircraft Air Carrier _____ *100%* _____

         Air Taxi _____ *100%* _____ General Aviation _____ *90%* _____

IFR Augmentation Factors:

     Air Carrier _____ *11.3% x 30% x 100% = 0.0339* _____

     Air Taxi _____ *11.3% x 30% x 100% = 0.0339* _____

     General Aviation *11.3% x 30% x 90% = 0.0305*

Avertable Flight Disruptions:	FY-1974 AIA's	IFR Aug. Factor	Avertable Flt. Disruptions
Air Carrier	2,023	.0339	69
Air Taxi	89	.0339	3
General Aviation/Military	1,089	.0305	33

Cost per Flight Disruption:	Cost Formula	Av. No. of Pass.	Cost per Disruption
Air Carrier	$48n + $293	18.1	$1,711
Air Taxi	50n + 9	6.3	324
General Aviation	15n + 12	5.0	87

Safety Benefit per Flt. Disr.	Benefit per IFR Approach	Safety Improvement Factor	Benefit per Disruption
Air Carrier	$20	9.8	$196
Air Taxi	49	9.8	480
General Aviation	20	9.8	196

Total Benefits FY-1974:	Total Benefit per Flight Disruption	Avertable Flight Disruptions	Total FY-1974 Benefits
Air Carrier	$1,367	69	$94,323
Air Taxi	804	3	2,412
General Aviation	283	33	9,339

Discounted 15-Year Benefits:	Total FY-1975 Benefits	Net Discount Factor	Discounted 15-Year Benefits
Air Carrier	$94,323	9.141	$862,207
Air Taxi	2,412	15.346	37,015
General Aviation	9,339	12.123	113,217
Total			$1,012,439

Benefit/Cost Ratio   15-year discounted benefits _____ *$1,012,439* _____
                        15-year discounted costs _____ *$ 772,000* _____
                        Ratio _____ *1.3* _____

the new minimums will permit. Sources of weather data
are discussed in Appendix C.

3. Estimate the proportionate use of the candidate runway
for instrument approaches, e.g., the runway on which the
first ILS at an airport is installed may handle 60 per-
cent of the instrument approaches at the airport, the
second ILS 30 percent, the third ILS 15 percent (since
there probably would be some realignment of runway use
with the additional ILS), etc. Requires regional input.

4. Estimate the proportion of instrument approaches that
will be by aircraft equipped to use the new ILS. (For
systems for which few aircraft are equipped such as the
Category IIIA ILS, the ISMLS, and the MLS, this will be
an important factor.)

5. Multiply 2. through 4. above, which gives an "IFR aug-
mentation factor," a measure of the proportion of flight
disruptions that will be averted by means of the new
facility.

6. List instrument approaches recorded at the airport, by
user category, during the most recent year and multiply
by the IFR augmentation factor. This gives the number of
averted flight disruptions.

7. Compute the cost per flight disruption by inserting the
average number of deplaning passengers (or passengers on
board) into the cost estimating equations developed in
Appendix A. May require regional input.

8. Compute the safety benefit per flight disruption by mul-
tiplying the benefit per IFR approach (Appendix B) by
the safety improvement factor associated with the increase
in runway utilization.

9. Sum the flight disruption and safety benefits and multiply
by the number of avertable flight disruptions. This gives
total benefits for the current year, by user category.

10. Multiply current year benefits by the net 15-year dis-
count factors, by user group, which gives lifetime
benefits.

11. Divide discounted 15-year benefits by costs to get the
benefit/cost ratio for the runway.

SECTION VIII - IMPACT ASSESSMENT

The revised criteria lower ILS establishment levels at air
carrier airports and raise them at general aviation airports.
The new criteria also explicitly recognize and give credit
for operations by air taxi aircraft.

One way to assess the impact of the revised criteria would
be to ask FAA's regional offices to identify, runway-by-
runway, those locations meeting the previous and revised ILS
(or MLS) criteria over the next 10 years. This procedure
would eliminate locations where an ILS is not feasible for
one reason or another; however, it is not practical at this
time. Alternatively, one can apply the two sets of criteria
to current and forecast instrument approach activity, as has
been done below. Revised ILS criteria associated with
reductions in minimums of from 500-1 and 400-1 to 200-½ were
selected as being representative of the average situation.

Locations meeting numeric criteria were identified by apply-
ing the previous and revised criteria to AIA's listed in
FAA's FY-1974 Air Traffic Activity report. Estimates of addi-
tional qualifiers through FY-1986 were obtained by deflating
establishment levels under the two sets of criteria by IFR
activity growth factors shown in official FAA forecasts (air
carrier - 1.3, air taxi - 2.6, general aviation - 2.0).

In applying the criteria, it was estimated that the first ILS
at an airport will handle 60 percent of the instrument
approaches; the second ILS 30 percent; and the third ILS
15 percent, since there probably would be some realignment
of runway use with the additional facilities. (It has been
argued that multiple ILS installations should be based on the
marginal improvement the ILS gives, i.e., if one ILS handles
60 percent of the AIA's and two ILS's 80 percent, the second
ILS gives a 20 percent improvement; if three ILS's handle
90 percent of the instrument approaches, the third gives a
10 percent improvement, etc. However, this reasoning is not
applicable here because the benefits given by an ILS are pro-
portional to the actual numbers of instrument approaches
served.)

By means of this procedure, locations meeting numeric cri-
teria have been identified. It should be noted that loca-
tions meeting numeric criteria are not necessarily candidates
for an ILS: The installation may not be technically feasible;
obstacles around the airport may preclude a precision approach;

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the airport sponsor may not be willing to prepare the site or provide the required runway length or lighting; or there may be community resistance to an ILS. The tabulation in Table 5, for example, lists 83 non-ILS runways that met the previous numeric criteria. In other words, identifying numeric qualifiers gives an estimate of the relative impact of the two sets of criteria but not of the absolute impact.

As background for an impact assessment, it may also be helpful to review the current ILS inventory, including systems budgeted for but not yet installed. All large- and medium-hub airports are well-equipped with ILS. Eighty-three of the 84 small-hub airports have ILS, and 32 have multiple systems. Of the nonhub air carrier airports, all but 4 recording 500 or more AIA's in FY-1974 have or are programmed for ILS. Finally, about 90 general aviation airports are equipped with ILS.

Large- and medium-hub airports were excluded from the impact assessment because these airports have enough instrument approach activity to justify ILS on practically every runway where it is needed. Airports qualifying for an initial ILS under the air carrier jet-use criterion were omitted because this criterion has not been changed. Previous and revised ILS criteria were applied to small-hub and nonhub air carrier airports and to general aviation/air taxi airports.

The results of this analysis are summarized in Table 5. In the short term, 81 additional air carrier runways and one additional general aviation runway meet the revised criteria. Over the next 10 years, potential candidates under the revised criteria are about 95 percent of those under the previous criteria. The reason for this is that although air carrier runway establishment levels have been relaxed, the number of potential air carrier candidates is limited.

TABLE 5

Numbers of Runways Meeting the Previous
and Revised ILS Establishment Criteria
for Specified Airport Types
FY-1976 and FY-1986

Type Airport, Year, and ILS	Estimated Number of Runways Meeting Numeric Criteria		
	Previous Criteria (P)	Revised Criteria (R)	R-P
Air Carrier Airports			
Medium and Small Hub			
FY-1976			
Second ILS	14	46	+32
Third ILS	15	48	+33
Add'l thru FY-1986			
Second ILS	12	8	- 4
Third ILS	13	12	- 1
Total	54	114	+60
Nonhub			
FY-1976			
First ILS	1	4	+ 3
Second ILS	5	18	+13
Add'l thru FY-1986			
First ILS	---	3	+ 3
Second ILS	8	5	- 3
Total	14	30	+16
General Aviation/Air Taxi Airports			
FY-1976			
First ILS	32	18	-14
Second ILS	16	31	+15
Add'l thru FY-1986			
First ILS	49	2	-47
Second ILS	43	4	-39
Total	140	55	-85
All Specified Airports			
FY-1976	83	165	+82
Add'l thru FY-1986	125	34	-91
Total	208	199	- 9

SECTION IX - SENSITIVITY ANALYSIS

Table 2 on page 16 gives some insight into the relative contributions of safety and efficiency benefits to the total. Efficiency benefits predominate for the air carriers. For general aviation and air taxi, safety benefits play a larger role.

Flight disruption benefits are principally dependent on four factors: (1) reduction in weather minimums, which determines the number of flight disruptions averted; (2) average number of deplaning passengers; (3) delay time caused by a disruption; and (4) the value of a passenger's time. The first two factors can be factually determined for any airport. For a sample of airports examined, these factors varied by as much as 10:1 and 7:1, respectively. They are the primary determinants of whether or not an ILS is justified. The third and fourth factors are based on our best estimates as outlined in Appendix A.

If the value of passenger time is halved (or the delay estimate halved, which has a similar impact), benefits are reduced from between 40 percent for large air carrier airports with 700-1 minimums on the candidate runway to 10 percent for general aviation runways with 300-3/4 minimums. This suggests that for air carrier airports the analysis is highly sensitive to the value of passengers' time. In the long run this would follow, of course, but in the short term most air carrier candidates exceed the qualifying levels by comfortable margins to that the effect of such a change would be lessened. At general aviation airports, safety benefits comprise a greater percentage of total benefits so reducing the value of passengers' time would have a minor impact.

With respect to safety benefits, substantial credit was taken for nonprecision approach accidents deemed preventable with the installation of an ILS. During the 10-year period studied, numbers of nonprecision approach accidents exceeded precision approach accidents by about 50 percent, and the nonprecision accidents resulted in more than twice as many fatalities. Offsetting nonprecision by precision approach accident costs would reduce air carrier establishment levels by from 5 to 20 percent, reduce air taxi establishment levels by from 15 to 35 percent, and reduce general aviation establishment levels by from 20 to 40 percent.

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APPENDIX A

COSTS OF FLIGHT DISRUPTIONS

Effects of Weather-Caused Flight Disruptions*

1. Air Carrier

Weather-caused flight disruptions--delays, diversions,
and cancellations--impose economic penalties on both
aircraft operators and passengers. Delays and diversions
increase aircraft operating costs. Cancellations result
in loss of revenue. All three types of disruptions create
extra passenger handling expense for the airlines. How-
ever, most of the costs of flight disruptions are borne
by the passengers, who suffer inconvenience and delay.
Since airports vary widely with respect to the numbers
of passengers they handle, average number of enplaned pas-
sengers is a variable in the flight disruption cost esti-
mating equations developed in this appendix.

In long-haul operations, airlines seldom cancel because
the destination airport is forecast to be closed. If on
arrival the destination airport is open or is forecast
to open within an hour or so, the aircraft will proceed
to its destination and either land or hold. Otherwise,
it will divert to another airport.

Short- and medium-haul flights tend to take delays on the
ground at the departure airport to save fuel and to ease
congestion problems at the arrival airport. This saves
equipment operating costs but not the cost of passenger
delay time. If the below-minimum weather at the destina-
tion is forecast to persist, the flight may be cancelled.
If the airport is an intermediate stop along a route, it
may be overflown, creating a diversion for passengers
intending to land and a cancellation for those expecting
to board the aircraft.

Airport size and facilities also affect flight behavior.
All large-, medium-, and small-hub** airports (except
Palm Springs, California) have one or more ILS's. Airport

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* The methodology used herein to estimate the costs of
weather-caused flight disruptions is an adaptation of that
developed by United Research Incorporated (References 5, 6)

** The air traffic hub structure as developed by FAA and used
to measure the concentration of civil air traffic by
communities.

closures will tend to be of shorter duration at these airports than at less well-equipped airports; and since large airports usually are served by larger aircraft, on the average, than small airports, costs of diversions and cancellations are relatively high. Consequently, flights into large airports are relatively more likely to be delayed, rather than diverted or cancelled, than flights into small airports. Because of these differences, separate flight disruption cost estimating equations have been developed for large airports (large, medium, and small hubs) and for small airports (nonhub).

Relative Frequency of Flight Disruptions. CAB statistics show that about 2.6 percent of air carrier departures scheduled at large-, medium-, and small-hub airports in CY-1973 were cancelled, while at nonhub airports the cancellation rate was 8.5 percent, or more than 3 times higher (Reference 3):

Hub Classification	Number of Hubs	CY-1973 Aircraft Departures Scheduled	Scheduled Completed* Number	Percent
Large	25	2,639,893	2,572,093	97.4
Medium	39	1,010,902	988,496	97.8
Small	84	675,043	651,772	96.6
Subtotal	148	4,325,838	4,212,361	97.4**
Nonhub	624	611,166	559,265	91.5
U. S. Total	772	4,937,004	4,771,626	96.7**

* Excludes extra sections of scheduled flights.
** Average percentage.

Fromm (Reference 6) determined several years ago that about two-thirds of air carrier cancellations, on an annual basis, were due to weather causes. He also found that air carrier diversions were about one-sixth as frequent as cancellations and that five-sixths of these diversions were caused by weather. These figures seem reasonable today and have been used here to estimate the

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proportions of cancellations and diversions at large-, medium-, and small-hub airports, as follows:

Weather-caused cancellations = 2.6% x 2/3

= 1.7% of all flights

Weather-caused diversions = 2.6% x 1/6 x 5/6

= 0.4% of all flights

Air Transport World magazine (Reference 7) has for a number of years published CAB data on the on-time arrival performance of the trunk air carriers. Averages for CY-1972 and CY-1973, weighted by numbers of scheduled departures per carrier, were as follows:

Performance Measure	Percentage	
	CY-1972	CY-1973
On-time or within 15 minutes	74.1	70.1
Over 15 minutes late	24.2	27.7
Cancelled flights	1.7	2.2
Total, trunk air carriers	100.0	100.0

This data indicates that delays to trunk air carrier aircraft are 12 to 14 times more frequent than flight cancellations. No information is available about the breakdown of these delays by cause, i.e., below-minimum weather, mechanical problems, late equipment, airport congestion, etc. However, delay data submitted by 3 airlines to the FAA over a 6-year period, 1964-1969, indicated that about 25 percent of delayed arrivals were delayed because of weather; about 2 percent of departing aircraft were reported delayed because of weather (Reference 8). (Although only one-fourth of total delays were attributed to weather, data collected by the FAA through its NASCOM program shows that of delays to IFR aircraft of over 30 minutes, about 50 percent are due to weather causes.)

Recapitulating, we have for fairly busy air carrier airports:

Weather-caused Flight Disruptions	Large Air Carrier Airports	
	Percent of All Flights	Normalized Distribution
Delays*	6.5*	75
Diversions	.4	5
Cancellations	1.7	20
Total	8.6	100

*26% of flights delayed times 25% of delays due to weather equals 6.5% of all flights delayed because of weather and associated congestion.

Based on the percentage of air carrier cancellations at nonhub airports (8.5 percent), 5 or 6 percent of flights scheduled into these airports may overfly the stop. Assuming the same percentage distribution of delays, diversions, and cancellations as for larger airports, but adding 5 percent overflights, gives for nonhub airports:

Weather-caused Flight Disruptions	Nonhub Air Carrier Airports	
	Percent of All Flights	Normalized Distribution
Delays	6.5	48
Diversions	.4	3
Cancellations	1.7	12
Overflights	5.0	37
Total	13.6	100

Aircraft Delays. An average delay of 45 minutes waiting for the weather to improve was applied to delayed air-craft. Weather conditions of the kind that prevail when an airport is closed (usually fog) often persist for several hours so that when delays are encountered, they tend to be rather lengthy. If the airport is forecast to be closed for several additional hours, flights may be cancelled or, if already airborne en route, diverted to an alternate airport.

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After the weather improves (it usually remains low visibility IFR), the queue which has built up must be reduced, and subsequent flights must take their turn in line. The net effect at a busy airport could easily be to more than double the average waiting time. In slow hours, or at less busy airports, this effect would be much smaller. For this analysis the average delay time was estimated to be 45 minutes at nonhub airports and 75 minutes at hub airports (45 minutes waiting for the weather to improve plus 30 minutes wait in queue). It was also assumed that 50 percent of the aircraft delays will be taken on the ground.

Aircraft Diversions. Diverting an aircraft from, say, Kennedy International to Dulles International Airport is a costly procedure. Additional flying time may be incured in holding over the original destination airport, in flying to an alternate destination, and, possibly, in holding over the alternate. When the weather improves, the aircraft usually must be ferried to another airport before it c.n resume normal scheduled operations. It is estimated that diversions require one hour extra flying time, averaged for all diversions including those that are diverted prior to entering the terminal area of the destination airport but excluding overflights which merely proceed to the next destination. Repositioning aircraft requires an estimated one-half hour ferry flight. Total additional flight time per diversion thus is 1½ hours.

Airlines also incur passenger service expense as a result of flight diversions. Passengers must be transported from the alternate airport to their intended destination, either on a later flight or by surface transportation. In some instances, meals and overnight lodging are provided. Per-passenger costs to the airlines for these expenses are estimated to average $30, including $25 for the return trip to the original destination plus a prorated average of $5 per passenger for those who must be fed, housed, or otherwise accommodated.

Finally, it is necessary to consider the time lost by passengers. One hour is lost because of additional flying time. To this must be added the additional amount of time required for the passenger to reach his desired destination. If the return trip is by air, an extra hour or so of flight time is involved plus perhaps 3 hours waiting for the destination airport to open. If surface Transportation is used, a similar amount of time is likely

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to be required to arrange for the alternate transportation and for the actual travel time. Total time lost due to a flight diversion thus adds up to 5 hours per passenger.

Flight Cancellations. When a flight is cancelled, the airline must arrange reservations on a future flight, if the passenger still wants to go, and issue new tickets. Meals must be provided some passengers and, occasionally, overnight lodging. These extra handling expenses, averaged for all passengers whether continuing their trip at a later time or not, are estimated to approximate $2 per passenger.

As with diversions, aircraft sometimes must be repositioned after a flight is cancelled. An average of one-half hour extra flying time for ferrying aircraft is assumed, the same as for diverted aircraft, and it is estimated that one-third of cancelled aircraft must be repositioned. Averaged for all cancellations, this yields 10 minutes' extra flying time per cancellation (one-half hour applied to one-third of the cancellations).

Airlines also are subject to losses of passenger revenue because some passengers may shift to other means of transportation and others may cancel their trip. The decision to cancel or not is influenced by many factors, including the length of the trip involved, whether the cancelled flight is the outbound or the return trip, the expected duration of below-minimum weather, the availability of alternative means of transportation, the purpose of the journey, etc. Based on discussions with airline personnel, Fromm (Reference 6) developed estimates of the percent of booked passenger revenue retained by air carriers, as a function of length of passenger journey. Since those estimates were developed, aircraft speeds have increased and the overall reliability of air transportation has improved. Consequently, Fromm's estimates have been revised, as follows:

Length of Flight	Percent of Booked Passenger Revenue Retained by Air Carriers	
	Fromm's Estimate	Revised Estimate
0 - 499 miles	30%	60%
500 - 999 miles	55%	75%
1,000 miles or over	80%	90%

Applying the preceding cancellation revenue retention percentages to passenger mile data gives an average rate of revenue retention of about 80 percent. This percentage was applied to cancellations at all airports, large and small, as a departure from a small airport often is but the first leg of a longer trip. Domestic airline passenger trip lengths averaged about 700 miles in FY-1974 (Reference 9) (international trips seldom are cancelled). At 10 cents per passenger mile, revenue per trip thus averages $70. With a revenue retention rate of 80 percent, the revenue loss attributable to a cancellation averages about $14 per passenger.

Revenue losses when flights are cancelled are offset by savings in direct aircraft operating costs of the potential flight. The average duration of a trunk air carrier aircraft flight in FY-1974 was 1.25 hours; for local service carriers flight durations averaged 0.58 hours (References 3, 10).

Trunk airlines typically operate from hub airports, whereas local service airlines are more representative of the kinds of activities found at nonhub, air carrier airports. Average aircraft operating costs are applied to these typical flight durations in the development of flight disruption cost estimating equations.

As with other kinds of flight disruptions, passengers are subjected to delay and a loss of productive time when a flight is cancelled. If the cancelled flight is the return portion of a long trip, the passenger has little recourse but to wait until the airlines start flying again. If, on the other hand, he is given ample notice of the cancellation, cancels his trip, and is able to adjust his schedule accordingly, he may suffer no delay.

Airlines seldom cancel flights on account of weather unless the weather is very poor and is forecast to remain so for several hours. As the flight that is cancelled may have been scheduled to depart some time during this period, the delay waiting for the weather to improve may average 2 hours. After the weather improves, passengers continuing their trips by air must find another flight going their way and get reservations. This can easily add 3 hours' or more additional delay. Assuming a total delay of 5 hours, on the average, when flights are cancelled, and applying this delay to 80 percent of cancelled passengers who elect to continue their trips by air, gives

an average of 4 hours' delay per cancelled passenger.
These long delay times may seem excessive, but is should
be noted that airlines ordinarily do not cancel flights
unless the destination airport (or if the weather is bad
enough, the departure airport) is forecast to be below
minimums for a considerable period of time. If closures
of shorter duration are forecast, they usually will delay
on the ground at the departure airport.

Overflights. An overflight does not increase aircraft
operating costs; in fact, when a stop is bypassed and the
aircraft proceeds directly to its next destination, total
flying time is reduced. These savings are offset in those
instances when the pilot holds for a few minutes over his
intended destination while he decides whether he should
or should not attempt a landing.

An overflight results in a diversion for passengers
intending to deplane and a cancellation for passengers
intending to board the aircraft. The airlines incur
extra passenger handling expenses when stops are over-
flown, just as they do with other diversions and cancel-
lations; and passengers, whether enplaning or deplaning,
experience delays. For these reasons, in this study an
overflight has been equated to a diversion plus a can-
cellation and, except for increased aircraft operating
costs, costed accordingly.

Secondary Effects of Delays. When an aircraft is delayed,
say an hour, the flight on which the equipment next goes
out (or the next leg of a continued flight) will also be
delayed. Equipment turnaround time, however, normally
includes slack time, say 15 minutes. By foregoing sched-
uled slack time at intermediate stops, delayed flights
are able to make up some lost time during subsequent
flights between city pairs. Nevertheless, passengers
boarding later flights would still have waited for the
delayed flight to arrive. Passengers waiting at airports
on the next one or two legs of the delayed flight would
experience practically as much delay as those on the pre-
ceding legs. If many intermediate stops are made, only
enplaning passengers at later legs will experience minor
delays.

The effect is essentially the same when an aircraft makes
stops on a through flight. Stops are generally scheduled
to take a minimum amount of time on the ground to minimize
inconvenience to passengers aboard the aircraft. In such

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cases, very little can be saved at a stop, and passengers who board the aircraft when it stops have the delay inflicted on them.

There are, however, integrating factors which offset the cumulative effect of delays. For one thing, delays will sometimes occur in the evening when an aircraft is through flying for the day or has but one or two more trips to make. Perhaps more important than the foregoing, airlines do not generally schedule equipment for the tight turnarounds suggested above. Indeed, they often permit rather large gaps in equipment schedules during the day. This is presumably done because of the vagaries of consumer demand--for example, equipment is frequently scheduled for departure on the hour or half-hour. The price airlines pay to give such service is less-than-full equipment scheduling. Customer demand also leads airlines to allow equipment to sit on the ground for extended periods during the day and in the late evening. The very existence of air carrier morning and early evening traffic peaks attests to the fact that airlines behave in this manner.

Finally, at the largest airports, airlines can often use other equipment to back up a flight that is delayed. Such reshuffling of equipment is one of a dispatcher's key functions; he may dead-head equipment that is temporarily idle to close a gap on a delayed flight.

For all of the foregoing reasons, it is an exaggeration to say that a flight delay at the initial leg of the trip will result in cumulative delays to subsequent passengers. In this analysis, it was assumed that 45 minutes of weather-caused delay at hub airports gives rise to 2 hours' passenger delay--45 minutes of weather delay plus 30 minutes in queue plus 45 minutes' delay to subsequent flights. At nonhub airports queues are unlikely, so it was assumed that 45 minutes of flight delay would result in a total of 1½ hours of passenger delay.

Secondary Effects of Diversions and Cancellations. The diversion of an aircraft frequently will result in a cancellation of the following trip on which the equipment was supposed to depart. However, because of considerations similar to those discussed above for delays, the outbound trip won't always be cancelled. In this study it was estimated that one-half of diversions result in subsequent cancellations. This estimate is consistent

with fragmentary information obtained from a couple of airlines. A similar estimate was made with respect to aircraft that cancel because of below-minimum forecasts for the destination airport. If the diversion or cancellation is caused by an overflight and the aircraft continues on to its next destination, there are no subsequent effects.

2. Air Taxi

Air taxi and commuter airlines operate in much the same manner as the certificated route air carriers but on a lesser scale. Operations are conducted with smaller aircraft and fewer passengers (an average of 6.3) are carried per flight. Stage lengths average 100 miles, roughly one-half hour's flying time, and fares run 15 to 20 cents per passenger mile (References 4, 11).

Little data exists about the behavior of air taxi aircraft operators when faced with weather-caused flight disruptions, or about the distribution of such disruptions. The distribution of air taxi aircraft flight disruptions probably is similar to that found for certificated route air carriers operating into nonhub airports. Because of the shorter stage lengths, however, and the greater availability of alternative means of transportation, delays associated with diversions and cancellations are less severe. For purpose of this report, it is estimated that the impact of delays on air taxi aircraft and passengers is similar to that experienced by the certificated route air carriers at nonhub airports, but that diversions and cancellations have only one-half the impact. When flights are cancelled, an estimated 70 percent of the potential air taxi passengers will cancel their trips or use another means of travel.

3. General Aviation

Most flight disruptions due to weather in general aviation are borne by business travelers flying in relatively large aircraft equipped for IFR operations. The pattern of flight disruptions experienced in general aviation probably is similar to that estimated for the trunk air carriers, except that there are few secondary effects of flight disruptions in general aviation. The impact of flight disruptions on passengers is less because the aircraft they are traveling in is available for use as soon as the weather clears. Because of the greater number

of airports that they can operate into, diversion times are less. Some interrupted trip expenses will be incurred for meals and overnight accommodations in some cases; these are estimated to average $15 per diverted passenger and $5 per cancelled passenger.

4. Summary of Flight Disruption Effects

Flight disruption effects are summarized in Table A-1 by type of disruption and aviation category. These effects are costed out in the following section.

Costs of Flight Disruptions

1. Air Carrier

The Civil Aeronautics Board publishes detailed statistics on air carrier aircraft operating costs and performance (Reference 10). One breakdown gives flying operations cost per block hour by type of aircraft for the domestic operations of domestic trunk airlines and for the local service airlines. Flying operations costs include crew, fuel and oil, insurance, and maintenance; depreciation costs are excluded. The latest published data is for CY-1973. Since then, fuel costs have doubled. Making that adjustment, the average hourly operations cost for domestic trunk aircraft is about $800 and for local service aircraft it is $425.

The other major cost factor used in this analysis is the value of passenger time lost, estimated at $12.50 an hour. This estimate is a combination of projected data developed by United Research, Inc. (Reference 6) and other related studies by consultants in the aviation field.

A number of letter symbols and subscripts are used in the cost estimating equations derived in the remainder of this section. Most of these fall out when equations are combined and do not reappear. For the convenience of readers who wish to follow the development of the individual equations, these symbols and subscripts are listed below:

C – cost	H – hub airport
DL – delay	N – nonhub airport
DV – diversion	A – air carrier
CL – cancellation	T – air taxi
O – overflight	G – general aviation

TABLE A-1

Summary of Flight Disruption Effects

Flight Disruption Effect	Hub Airport	Nonhub Airport	Air Taxi	General Aviation
Extra Aircraft Flight Time (Hours)				
Delays				
Primary*	3/8	3/8	3/8	3/8
Queue Reduction	1/2	---	---	---
Total	7/8	3/8	3/8	3/8
Diversions				
Primary	1	1	1/2	1/2
Repositioning Aircraft	1/2	1/2	1/4	---
Total	1-1/2	1-1/2	3/4	1/2
Cancellations				
Repositioning Aircraft	1/6	1/6	---	---
Passenger Time Lost (Hours)				
Delays				
Primary	3/4	3/4	3/4	3/4
Queue Reduction	1/2	---	---	---
Secondary	3/4	3/4	3/4	---
Total	2	1-1/2	1-1/2	3/4
Diversions				
Primary	5	5	2-1/2	2-1/2
Secondary	2-1/2	2-1/2	1-1/4	---
Total	7-1/2	7-1/2	3-3/4	2-1/2
Cancellations				
Primary	4	4	2	2
Secondary	2	2	1	---
Total	6	6	3	2
Overflights				
Diverted Passengers	---	5	2-1/2	---
Cancelled Passengers	---	4	2	---
Passenger Handling Expense				
Delays	$--	$--	$--	$--
Diversions	30	10	15	15
Cancellations	10	10	5	5
Revenue Loss Due to Cancellations	20%	20%	70%	---

*An estimated 50% of aircraft delay is taken on the ground at the departure airport.

For example, the symbol C_{DL-AH} represents the cost of delaying an air carrier aircraft at a hub airport.

Delay Costs

a. <u>Hub Airports</u>. Airline delay costs equal 50 percent of 45 minutes per delayed aircraft plus 30 minutes for queue reduction, at $800 per hour, or $700 per delayed aircraft.

Passenger delays, primary plus secondary effects, equal 2 hours per passenger (45 minutes of weather delay plus 30 minutes' queue reduction plus 45 minutes' secondary effects). At $12.50 an hour, this equals $25 per passenger which, when multipled by the number of passengers (n) deplaning*, gives the total cost of passenger delay time. The total cost per delayed air carrier aircraft at hub airports (C_{DL-AH}) thus is estimated to be:

$$C_{DL-AH} = \$25n + \$700$$

where n = number of deplaning passengers.

The above procedure does not allow for delays to passengers continuing their trips on the delayed aircraft. The average airline passenger trip includes two landings, i.e., only about one-half of the passengers disembark at a given stop. The proportion disembarking will be higher at major airports, of course, and lower at small airports. This factor has been omitted from the estimates of delay costs at hub airports; it is reflected, however, in the estimates of delay costs at nonhub airports.

b. <u>Nonhub Airports</u>. Fifty percent of 45 minutes per delayed aircraft, at $425 an hour, equals $159 per delayed aircraft.

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*Deplaning passengers equal enplaning passengers on the average. Average numbers of enplaned passengers per departure can be derived from data published in Airport Activity Statistics of the Certificated Route Air Carriers (Reference 3).

Cumulative delays of 1½ hours per passenger at $12.50 per hour equals $18.75 per delayed passenger. At least one-half and usually more of the passengers on a flight into a small airport are through passengers, i.e., they remain on the aircraft; these passengers will also be delayed, of course. To account for this factor in total passenger delay costs, multiply the number of deplaning passengers by 2 and the product by $18.75 per delayed passenger. The total cost per delayed passenger at nonhub airports (C_{DL-AN}) is then:

$$C_{DL-AN} = 2(\$18.75)n + \$159$$

$$= \$37.50n + \$159$$

where n is the number of deplaning passengers.

Cancellation Costs

a. <u>Hub Airports</u>

Per aircraft

Repositioning aircraft (1/6 of $800)	$ 133.33
Less direct operating savings (1.25 hours @ $800)	(1,000.00)
Total	$ 866.67

Per passenger

Extra handling expense	$ 10.00
Revenue loss	70.00
Less revenue recovered (at 80%)	(56.00)
Lost time (4 hours @ $12.50)	50.00
Total	$ 74.00

One-half of the cancellations lead to subsequent cancellations, so the costs associated with an air carrier cancellation at a hub airport (C_{CL-AH}) are:

$$C_{CL-AH} = 1\text{-}1/2(\$74.00n - \$866.67)$$

$$= \$111n - \$1300$$

where n is the number of deplaning passengers.

b. Nonhub Airports

Per aircraft

Repositioning aircraft	$ 70.83
Less direct operating savings (0.58 hour at $425)	(246.50)
Total	($175.67)

Per passenger

Extra handling expense	$ 10.00
Revenue loss	70.00
Less revenue recovered (at 80%)	(56.00)
Lost time (4 hours at $12.50)	50.00
Total	$ 74.00

Since one-half of these cancellations are expected to lead to subsequent cancellations, the total costs associated with an air carrier cancellation at a non-hub airport (C_{CL-AN}) are:

$$C_{CL-AN} = 1\text{-}1/2 (\$74.00n - \$175.67)$$

$$= \$111n - \$263$$

where n is the number of deplaning passengers.

Diversion Costs

a. Hub Airports

Per aircraft

In-flight delays (1 hour @ $800)	$ 800.00
Repositioning aircraft (1/2 hour @ $800)	400.00
Total	$1,200.00

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Per passenger

Extra handling expense	$	30.00
Lost time (5 hours @ $12.50)		62.50
Total	$	92.50

Estimating that one-half of all diversions lead to subsequent cancellations, we have as the cost of an air carrier aircraft diversion from a hub airport (C_{DV-AH}):

$$C_{DV-AH} = \$92.50n + \$1,200 + 1/2(\$111n - \$1,300)$$

$$= \$148n + \$550$$

where n is the number of deplaning passengers.

b. **Nonhub Airports**

Per aircraft

In-flight delays (1 hour @ $4.25)	$425.00
Repositioning aircraft (1/2 hour @ $425)	212.50
Total	$637.50

Per passenger

Extra handling expense	$	30.00
Time lost (5 hours @ $12.50)		62.50
Total	$	92.50

If one-half of these diversions lead to subsequent cancellations, we have for the costs associated with the diversion of an air carrier aircraft from a non-hub airport (C_{DV-AN}) the following:

$$C_{DV-AN} = \$92.50n + \$637.50 + 1/2(\$111n - \$263)$$

$$= \$148n + \$506$$

where n is the number of deplaning passengers.

Overflight Costs. Overflight costs apply at nonhub airports only. No aircraft operating costs are included and there are no subsequent effects of overflights. Passenger costs associated with an overflight included:

Diverted passengers

Passenger handling expenses	$30.00
Lost time (5 hours @ $12.50)	62.50
Total	$92.50

Cancelled passengers

Passenger handling expense	$10.00
Lost time (4 hours @ $12.50)	50.00
Revenue loss	70.00
Less revenue recovered (at 80%)	(56.00)
Total	$74.00

The total cost of an overflight (C_O) thus is:

$$C_O = n(\$92.50 + \$74)$$

$$= \$166.50n$$

where n is the number of passengers.

Summary Air Carrier Flight Disruption Costs. Total estimated costs associated with weather-caused disruption of air carrier flights can now be determined by weighing the cost of each type of disruption by its proportional frequency of occurrence and combining costs, as follows:

a. Hub Airports

Disruption	Cost Equation	Weight
Delays	$ 25n + $ 700	0.75
Cancellations	111n - 1,300	.20
Diversions	148n + 550	.05
All Disruptions	$48.35n + $293	1.00

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The average cost of air carrier flight disruptions at hub airports (C_{A-H}) thus is estimated to be:

$$C_{A-H} = \$48n + \$293$$

where n is the number of deplaning passengers.

If the approach-and-landing aid under consideration is one used by large aircraft only, as in the case of the Category IIIA ILS, aircraft operating costs used in the cost estimating equations should be adjusted accordingly.

b. Nonhub Airports

Disruption	Cost Equation	Weight
Delays	$ 37.50n + $159.00	0.48
Cancellations	111.00n – 263.00	.12
Diversions	148.00n + 506.00	.03
Overflights	166.50n	.37
All Disruptions	$ 97.37n + $ 60.00	1.00

So for the average cost of air carrier flight disruptions at nonhub airports (C_{A-N}) we have:

$$C_{A-N} = \$97n + \$60$$

where n is the number of enplaned passengers.

2. Air Taxi

Based on data published in References 4 and 11, flying operations costs for air taxi aircraft (excluding depreciation) are estimated to approximate $60 an hour. Passenger fares average $17.25 per trip, and it is estimated that only 30 percent of this potential revenue is recovered when a trip is cancelled. Air taxis are subject to the same kinds of flight disruptions as the certificated route carriers but, because of the shorter stage lengths

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flown, the effects of cancellations and diversions are estimated to be only one-half as severe. No distinction is made between air taxi flight disruptions at hub and nonhub airports. It is estimated that extra handling expenses average $15 per diverted passenger and $5 for cancelled passenger. The value of air taxi passenger time lost due to weather-caused flight disruptions is set at $12.50 per hour. Applying the above factors, where appropriate, to the flight disruption effects developed earlier yields the following estimates of the costs of air taxi flight disruptions.

Delay Costs. Air taxi aircraft delay costs average 3/8 of an hour per delay at $60 an hour, or $22.50 per delay. Passengers are delayed an estimated 1½ hours each on the average, including secondary effects, at a cost of $18.75. The total cost per delayed air taxi aircraft (C_{DL-T}) is thus estimated to be:

$$C_{DL-T} = \$18.75n + \$22.50$$

where n is the number of deplaning passengers.

Cancellation Costs. The cancellation of an air taxi flight saves the cost of operating the aircraft (½ hour at $60 equals $30). Estimated costs per cancelled passenger are:

Extra handling expense	$ 5.00
Passenger time lost (3 hours @ $12.50)	37.50
Revenue loss	17.25
Less revenue recovered (at 30%)	(5.18)
Total	$54.57

The effects of subsequent cancellations have been reflected in the average time lost per passenger, so we have as the average cost of an air taxi cancellation (C_{CL-T}):

$$C_{CL-T} = \$54.57n - \$30.00$$

where n is the number of deplaning passengers.

Diversion Costs. An additional 3/4 hour aircraft operating time costs $45. Passenger costs include $15 extra handling expense plus 3-3/4 hours (including secondary effects) of passenger time lost at $12.50 an hour, for a total of $61.88 per passenger. Total estimated air taxi diversion costs (C_{DV-T}) are:

$$C_{DV-T} = \$61.88n + \$45.00$$

where n is the number of deplaning passengers.

Overflight Costs

Per cancelled passenger

Extra handling cost	$ 5.00
Time lost (2 hours @ $12.50)	25.00
Revenue loss	17.25
Less revenue recovered (at 30%)	(5.18)
Total	$42.07

Per diverted passenger

Extra handling expense	$15.00
Time lost (2-1/2 hours @ $12.50)	31.25
Total	$46.25

$$C_{O-T} = n(\$42.07 + \$46.25) = \$88.32n$$

where n is the number of enplaned passengers.

Summary Air Taxi Flight Disruption Costs. Weighing each kind of air taxi flight disruption cost by the distribution of flight disruptions found to apply at nonhub airports gives:

Disruption	Cost Equation	Weight
Delays	$18.75n + $22.50	0.48
Cancellations	54.57n - 30.00	.12
Diversions	61.88n + 45.00	.03
Overflights	88.32n	.37
All Disruptions	$50.08n + $ 8.55	1.00

The average cost of a weather-caused air taxi flight disruption (C_T) therefore is estimated to be:

$$C_T = \$50n + \$9$$

where n is the number of deplaning passengers.

3. General Aviation

As was noted earlier, most flight disruptions due to weather in general aviation are borne by business travelers flying in relatively large aircraft equipped for IFR operations. Flying operations costs for this type of aircraft are estimated at $40 an hour or roughly equivalent to those of a light twin aircraft. Interrupted trip expenses were estimated to approximate $15 per diverted passenger and $5 per cancelled passenger. There are few secondary effects of general aviation flight disruptions, and no distinction has been made between general aviation flight disruptions at hub and nonhub airports.

Delay Costs. An extra 3/8 hour's flying time was assumed to apply to the average general aviation aircraft delay. At $40 an hour, this equals $15 per delay. Passenger delays average 3/4 hour at $12.50 per hour, or $9.38. Total costs of general aviation delays (C_{DL-G}) due to weather thus average:

$$C_{DL-G} = \$9.38n + \$15$$

where n is the number of persons on board.

Cancellation Costs. No additional aircraft flying time is involved. Passenger costs average $5 extra handling expense plus 2 hours' delay at $12.50 an hour for a total of $30.

$$C_{CL-G} = \$30n$$

where n is the number of persons on board.

Diversion Costs

Per aircraft

1/2 hour's extra flying time @ $40	$20.00

Per passenger

Extra handling expense	$15.00
2-1/2 hours' delay @ $12.50	31.25
Total	$46.25

$$C_{VD-G} = \$46.25n + \$20$$

where n is the number of persons on board.

Summary of General Aviation Flight Disruption Costs. Weighing general aviation flight disruption costs by their expected frequency of occurrence we have:

Disruption	Costs Equation	Weight
Delays	$ 9.38n + $15	0.75
Cancellations	30.00n	.20
Diversions	46.25n + 20	.05
All Disruptions	$15.35n + $12	1.00

Summary of Weather-Caused Flight Disruption Costs. Recapitulating, we have for the average costs of flight disruptions:

Air Carrier

Hub airport	$48n + $293
Nonhub airport	97n + 60

Air Taxi	50n + 9

General Aviation	15n + 12

where n is the number of deplaning passengers.

Numbers of passengers is a variable in all of these equations. Actual data should be used to estimate the costs of flight disruptions if it is available. For broad planning purposes, we can estimate the average number of passengers deplaning each type of flight and convert the cost equations to average dollar values, as follows:

Type of Flight	Average Number of Deplaning Passengers*	Average Cost per Flight Disruption
Air Carrier		
Large hub	54.0	$2,885
Medium hub	38.1	2,120
Small hub	29.7	1,720
Nonhub	8.1	845
Air Taxi	6.3	325
General Aviation	5.0	90

*Average number of deplaning air carrier passengers derived from CAB/FAA Airport Activity Statistics (Reference 3); air taxi passengers from CAB Commuter Air Carrier Traffic Statistics (Reference 4); passengers, including crew, aboard general aviation IFR flights estimated from itinerant flight survey data.

APPENDIX B

SAFETY BENEFITS

Simpson (Reference 12) recently completed a detailed analysis of civil aviation accidents between January 1964 and December 1972. One section of his report covered landing accidents and, in particular, he searched the entire NTSB data base for accidents which happened under circumstances where it could be hypothesized that at least some of the accidents might have been avoided if precision approach facilities had been available and used. The benefits of preventable landing accidents developed in this appendix are based on Simpson's statistics.

During the period January 1964 through December 1972, there were 18,602 landing accidents resulting in 1,627 fatalities within the conterminous 48 United States under "normal" operating conditions (i.e., excluding abnormal operating conditions such as impaired pilot and aircraft failure or malfunction). These accidents were categorized by Simpson as instrument approach accidents, visual approach accidents, and runway accidents (Figure B-1). Numbers of accidents and fatalities within each of the categories between 1964 and 1972 are shown by user class in Table B-1.

TABLE B-1

Landing Accidents and Fatalities
by Type of Accident and User Class
48 Conterminous States
January 1964 - December 1972

Accident Category	Landing Accidents/Fatalities			
	Air Carrier	Air Taxi	General Aviation	Total
Instrument Approach				
Precision	22/86	19/6	67/70	108/162
Nonprecision	13/166	21/49	123/121	157/336
Visual Approach	54/300	287/32	11,048/786	11,389/1,118
Runway	35/0	117/0	6,796/11	6,948/11
Total	124/552	444/97	18,034/988	18,602/1,627

LANDING ACCIDENTS

A=18,602
F=1627

RUNWAY
A=6948 (37.4%)
F=11 (0.7%)

INSTRUMENT APPROACH
A=265 (1.4%)
F=498 (30.6%)

VISUAL APPROACH
A=11,389 (61.2%)
F=1118 (68.7%)

PRECISION
A=108 (0.5%)
F=162 (10.0%)

NON-PRECISION
A=157 (0.9%)
F=336 (20.6%)
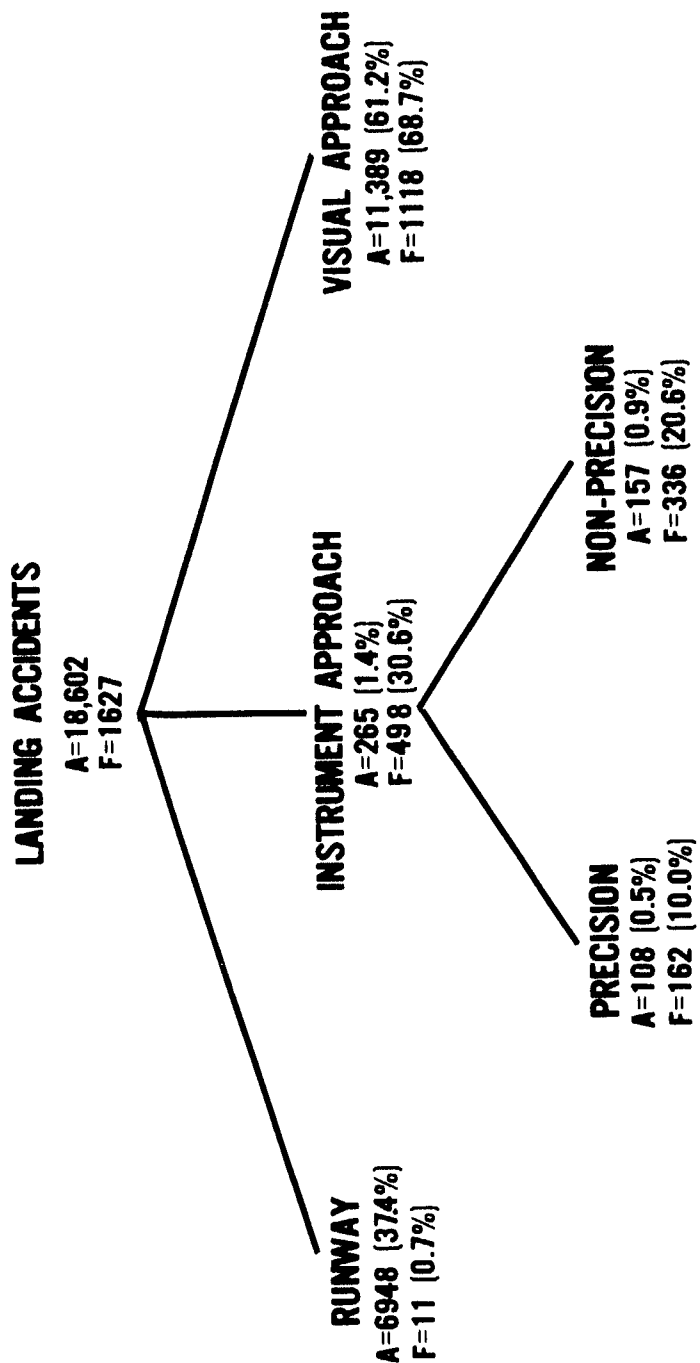
FIGURE B-1. -- LANDING ACCIDENTS WITHIN THE CONTERMINOUS UNITED STATES

JANUARY 1964 - DECEMBER 1972

Benefits of preventable instrument approach accidents are estimated for each major user group. This category of accident includes those that occurred while on a circling approach in IFR weather, i.e., certain visual approach accidents, as well as nonprecision approach accidents. Only those accidents judged to have been possibly avoidable with an ILS were included in the benefit calculations.

Benefits of preventable VFR visual approach accidents and runway accidents, two other important landing accident categories, have been estimated for general aviation but not for air carrier or air taxi. This was done because nominally preventable general aviation landing accidents of these kinds represent a significant proportion of total general aviation aircraft accidents and fatalities. For air carrier and air taxi aircraft this category of accident is relatively less important.

Substantial benefit credit has been given for potentially preventable accidents despite the fact that some of these accidents might have occurred if better guidance information had been available. This was done for two reasons. First, the benefit analysis has been limited to those accidents that have been judged as being possibly avoidable had better approach-and-landing aids been available.

The second and perhaps more important reason is a risk avoidance argument. Utility theory holds that decision makers will invest a dollar with the knowledge that less than a dollar will be returned if they wish to avoid potential adverse consequences, i.e., if they are risk avoiders. There is evidence that Congress and the public are risk avoiders with respect to aviation safety, that in their eyes safety benefits weigh more heavily than economic benefits. Investments in landing aids are a form of insurance against potentially disastrous accidents and, as such, conform both to public sentiment and to FAA policy, which places safety above all other considerations.

This reasoning also pertains to the present Airway Planning Standard criterion which states that "An airport where scheduled air carrier turbojet operations are conducted on a sustained basis...is a candidate for a Category I ILS with an approach light system..." Proper alignment on approach is especially critical with large turbojet aircraft because of their size, speed, and relatively slow response times. The National Transportation Safety Board has recommended that some sort of vertical guidance, ILS or VASI, be provided on

all runways serving air carrier jet aircraft. For these reasons, and because of the high costs of air carrier accidents, the air carrier jet-use criterion for ILS has been retained.

Costs of IFR Landing Accidents Partially Avoidable by Precision Approach Facilities

As part of his analysis of aircraft accident data, Simpson (Reference 12) searched the entire NTSB Data Base for accidents which happened under circumstances where it could be hypothesized that at least some of the accidents might have been avoided if precision approach facilities had been available and used. Specifically, the NTSB Data Base was searched for accidents which involved any one of the following conditions:

1. An undershoot and crash while on final approach in IFR weather;

2. Crashed after executing a missed approach in IFR weather;

3. Crashed while on a circling approach in IFR weather.

Two other types of accidents, overshoots and stalls, were also investigated to find out if they might have been prevented by a precision approach, but an initial analysis indicates that they probably could not have been.

The total number of accidents and fatalities occurring during visual and nonprecision instrument approaches under one of the three conditions identified above are shown in Table B-2.

TABLE B-2

Landing Accidents under Instrument Approach Conditions
That Might Have Been Prevented by a Precision Approach Aid
by User Group, Conterminous United States
1964 through 1972

User Group	Accidents	Fatalities	Fatalities/ Accidents
Air Carrier	6	48	8.0
Nonprecision Approach	6	48	8.0
Air Taxi	25	49	2.0
Nonprecision Approach	20	43	2.2
Visual Approach	5	6	1.2
General Aviation	117	111	0.9
Nonprecision Approach	55	79	1.4
Visual Approach	62	32	.5

Estimates of the safety benefits provided by an ILS through
the prevention of IFR approach accidents have been estimated
by, first, converting the number of accidents and fatalities
given above into accident rates and, second, estimating acci-
dent costs. Multiplying accident costs by the probability
of an accident (or dividing by the average number of approaches
between accidents) gives a measure of the benefit provided by
a precision approach aid through prevention of this kind of
accident.

Determining the probability of a nonprecision approach acci-
dent requires some knowledge of the number of nonprecision
approaches that were made. The FAA records total instrument
approaches by airport and user group but does not distinguish
between precision and nonprecision approaches. However, pro-
portionate precision and nonprecision approaches can be esti-
mated by examining the distributions of instrument approaches
by airport type. This data for CY-1973 is given in Table B-3.

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TABLE B-3

Instrument Approaches by Hub Type*
and Civil User Group
CY-1973

| Hub Type | Instrument Approaches (Thousands) | | | | | |
| | Air Carrier | | Air Taxi | | General Aviation | |
	No.	%	No.	%	No.	%
Large	442	51.6	50	30.5	78	11.0
Medium	177	20.7	19	11.6	95	13.4
Small	125	14.6	23	14.0	130	18.4
Nonhub	112	13.1	72	43.9	404	57.2
Total	856	100.0	164	100.0	707	100.0

* Hub classification is determined by an airport's percentage of total enplaned revenue passengers by the certificated route air carriers.

All hub airports but one are equipped with ILS, as are a number of nonhub airports. Large- and medium-hub airports usually have multiple ILS's. Bearing in mind that an instrument approach is counted only if the aircraft is on an IFR flight plan and IFR weather conditions prevail, it is estimated that the following proportions of instrument approaches were precision approaches in FY-1973: Large-hub airports - 90 percent; medium-hub airports - 75 percent; small-hub airports - 60 percent; nonhub airports - 20 percent. Applying these percentages to the numbers of instrument approaches in Table B-3 gives the following proportions of precision and nonprecision approaches by user group in 1973 (the general aviation percentages have been adjusted by 10 percent to allow for the fact that not all general aviation aircraft flying IFR are ILS-equipped):

User Group	Precision Approaches	Nonprecision Approaches
Air Carrier	73%	27%
Air Taxi	53%	47%
General Aviation	38%	62%

About one-fourth fewer ILS's were operational during the
1964-1972 period than in 1973, although all high-density
airports were well-equipped. For the computation of acci-
dent rates during 1964-1972, therefore, the preceding non-
precision approach percentages have been increased to: Air
carrier - 30 percent; air taxi - 50 percent; general avia-
tion - 65 percent.

Nonprecision approach accident rates are developed in Table B-4.
For the period from 1964 through 1972, total instrument
approaches by user group were taken from FAA Air Traffic
Activity Reports. Air taxi instrument approaches were not
counted separately prior to 1972. In that year and in 1973
air taxi represented about 19 percent of the combined total
of air taxi plus general aviation instrument approaches. On
that basis, air taxi instrument approaches were estimated to
be 19 percent of the general aviation total for the years
1964 through 1971.

TABLE B-4

Preventable Nonprecision Approach Accident Rates
by User Group
1964-1972

User Group	Total Instrument Approaches 1964-1972	Nonprecision Approaches Percent	Nonprecision Approaches Number	Preventable Nonprecision Approach Accidents*	Approaches per Accident
Air Carrier	7,094,000	30	2,128,000	6	355,000
Air Taxi	810,000	50	405,000	25	16,000
General Aviation	3,454,000	65	2,245,000	117	19,000

*From Table B-2

Accident costs include loss or damage to property and loss or
injury to human life. Aircraft replacement costs average
about $6,000,000 for air carrier aircraft, $200,000 for air
taxi aircraft, and $50,000 for general aviation aircraft. As
nonprecision approach accidents often result in total destruc-
tion of the aircraft, it is estimated that loss or damage to
aircraft averages 90 percent of replacement cost in these
instances.

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Aircraft accident fatalities have been costed at $300,000 each. This estimate was based on values developed by FAA's Office of Aviation Policy and Plans for use in benefit/cost studies. The basic data was obtained from the Civil Aeronautics Board and is based on non-Warsaw payments during the period 1966 to 1970, projected from the base period to 1975.

Estimated nonprecision approach accident costs are shown in Table B-5. The value of lives lost was determined by multiplying the value of a life ($300,000) by the average fatalities per accident given in Table B-2. As data on number of injuries in accidents of this kind is not readily available, this factor has been omitted; accident costs are underestimated to that extent.

TABLE B-5

Average Costs of
Preventable Nonprecision Approach Accidents
by User Group
FY-1975

User Group	Aircraft Losses	Value of Lives Lost	Average Costs per Accident
Air Carrier	$5,400,000	$2,400,000	$7,800,000
Air Taxi	180,000	600,000	780,000
General Aviation	45,000	270,000	315,000

Dividing accident costs from Table B-5 by average numbers of approaches between accidents from Table B-4 gives the average "risk cost" per nonprecision approach. This cost is a measure of the benefit that a precision approach aid could provide by preventing accidents of this type. These benefits are given in Table B-6.

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TABLE B-6

Benefits of Preventing Nonprecision Approach Accidents
by User Group

User Group	Approaches per Accident	Average Costs per accident	Potential Benefits per Precision Approach
Air Carrier	355,000	$7,800,000	$22
Air Taxi	16,000	780,000	49
General Aviation	19,000	315,000	17

The air carrier safety benefits in Table B-6 are averaged
for all preventable accidents, regardless of aircraft size
or numbers of passengers aboard. The effects of these two
factors can be approximated by proportioning air carrier
safety benefits to the costs of air carrier flight disruptions
developed in Appendix A, which reflect airport size and activity, as follows:

Hub Type	Costs of Air Carrier Flight Disruptions		Benefit per Preventable Air Carrier Approach Accident
	Dollars	Ratio to Average	
Large	$2,885	1.52	$33
Medium	2,120	1.12	25
Small	1,720	.91	20
Nonhub	845	.45	10
Average	$1,892	1.00	$22

Costs of Preventable General Aviation VFR Accidents

As part of his analysis of accident data, Simpson (Reference 12)
also made a preliminary sorting (without a manual analysis) of
the 10,813 small general aviation accidents that occurred
during a visual approach. Of these, 1,681 accidents with

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185 fatalities were undershoots on final approach, and 306 accidents with 5 fatalities were collisions with ground, water, or an object while the aircraft was flaring. Simpson hypothesized that some part of such accidents might have been avoided if a visual glide slope such as that provided by a VASI had been available; similar guidance is given by an ILS if the aircraft is ILS-equipped. At $300,000 per fatality and $25,000 aircraft damange per accident (50 percent of a replacement cost of $50,000), total costs of these accidents over the 9-year period approximated $107 million, in 1975 dollars.

Another 6,684 runway accidents were sustained by small general aviation aircraft during the study period. Accidents of this kind often are due to the pilot's failure to align his aircraft properly with the runway during final approach. Vertical guidance during the approach, given by either an ILS or a VASI, would help the pilot keep the aircraft on the proper glide path and set up a stabilized approach. Runway accidents seldom are as serious as approach accidents; the 6,684 general aviation accidents between 1964 and 1972 resulted in only 11 fatalities. By definition, however, all of these aircraft suffered substantial or greater damage. At an average cost of $2,500, repair of these aircraft cost about $17 million. Total costs of VFR general aviation landing accidents between 1964 and 1972 thus approximated $125 million, in 1975 dollars.

General aviation pilots made some 75 million itinerant and 87 million local landings at FAA tower airports between 1964 and 1972. Perhaps another 50 percent were made at nontower airports, for a total of some 250 million landings. Dividing the $125 million cost by 250 million landings gives a "risk cost" of about $0.50 per landing.

The benefit of an ILS or VASI in preventing general aviation VFR landing accidents, therefore, is 50 cents per landing. This benefit should be applied only to VFR aircraft on itinerant flights. Pilots doing local pattern work usually approach the runway at a steeper angle than that defined by the ILS or VASI.

Air carrier, air taxi, and large general aviation aircraft of the corporate/executive type also occasionally have accidents of these kinds. Such accidents typically are of relatively minor importance, however, and their costs have not been estimated here.

Summary of Safety Benefits

The benefit of an ILS (or VASI) in preventing general aviation VFR landing accidents is estimated to approximate $0.50 per itinerant aircraft landing. FAA statistics show that about one-fourth of the general aviation fleet is equipped with glide slope. If the pilots of these aircraft use the glide slope while making VFR approaches, the benefit of an ILS for the prevention of VFR landing accidents is about 12 cents per itinerant landing, averaged for all itinerant landings.

General aviation pilots made 722,000 instrument approaches in FY-1974, and it is estimated that they made about 18 million itinerant landings that year, 12 million at FAA tower airports and perhaps half as many at nontower airports. The ratio of itinerant landings to instrument approaches thus was about 25-to-1. Using this estimate, we can combine total ILS safety benefits into a single estimate for each user group in a manner that relates these benefits to benefits per instrument approach, as follows:

User Category	Benefits of Preventable:		Total Safety
	IFR Approach Accidents	VFR Landing Accidents	Benefits per IFR Approach
Air Carrier			
Large Hub	$33	$*	$33
Medium Hub	25	*	25
Small Hub	20	*	20
Nonhub	10	*	10
Air Taxi	49	*	49
General Aviation	17	3	20

*Estimated to amount to 1 percent or less of the benefits of preventable IFR approach accidents.

To determine the total safety benefits provided by an ILS, multiply the number of instrument approaches expected to be made with the ILS by the benefit per approach.

APPENDIX C

SOURCES OF WEATHER DATA

Percentages of hourly weather observations falling within
specified ceiling-visibility categories have been tabulated
for the FAA by the National Climatic Center at Asheville,
North Carolina, for the 271 airports listed at the end of
this appendix. Data for any of the 271 airports will be fur-
nished on request by ASP-110. More detailed data for the
airports is available on magnetic tape.

This data in the report is in the following format:

STATION#14944 SIOUX FALLS, S. D.   PERIOD OF RECORD 1/48-12/64

HOUR GROUP	NO.OF OBS	CEILING-VISIBILITY CATEGORIES (%)						SYSTEM ENHANCEMENT FACTORS (%)			
		(1)	(2)	(3)	(4)	(5)	(6)	VOR	CAT1	CAT2	MIN*
JAN ALL	12646	82.8	17.2	12.7	2.8	0.9	0.9	73.8	16.1	5.0	5.0
FEB "	11542	79.4	20.6	14.9	2.9	1.0	1.8	72.3	14.2	4.9	8.6
MAR "	12645	80.2	19.8	15.0	2.9	0.8	1.1	75.8	14.6	3.9	5.7
APR "	12236	87.5	12.5	11.1	1.1	0.2	0.2	89.0	8.4	1.2	1.4
MAY "	12647	89.4	10.6	9.7	0.8	0.1	0.0	91.1	7.6	0.9	0.4
JUN "	12239	92.6	7.4	6.8	0.5	0.1	0.1	91.2	6.3	1.2	1.3
JUL "	12647	95.3	4.7	4.2	0.3	0.1	0.1	89.8	5.4	2.4	2.4
AUG "	12648	93.6	6.4	5.2	0.9	0.1	0.2	81.7	13.4	2.0	3.0
SEP "	12239	91.3	8.7	7.3	0.7	0.2	0.4	84.4	8.3	2.6	4.6
OCT "	12646	90.0	10.0	8.1	0.9	0.4	0.7	81.0	8.6	3.7	6.7
NOV "	12237	87.4	12.6	9.7	1.4	0.6	0.9	76.9	11.0	4.9	7.2
DEC "	12647	79.8	20.2	15.4	2.8	1.0	1.1	76.3	13.6	4.7	5.3
ANN 07-13	43463	84.4	15.6	12.9	1.7	0.4	0.6	82.7	11.1	2.6	3.5
14-21	49676	90.4	9.6	8.1	1.0	0.2	0.2	84.7	11.0	2.0	2.3
22-06	55880	87.3	12.7	9.4	1.6	0.7	1.0	73.6	12.9	5.5	8.0
ALL	149019	87.5	12.5	10.0	1.5	0.4	0.6	79.8	11.8	3.6	4.9

CEILING VISIBILITY CONDITIONS (% OF TOTAL OBSERVATIONS)   SYSTEMS ENHANCEMENT FACTORS
                                                                  (CEILING VISIBILITY CONDITIONS)

(1) ≥ 1500 FEET AND 3 MILES

(2) < 1500 FEET AND/OR 3 MILES   VOR=FREQ (3)/FREQ(2)

(3) < 1500 FEET AND/OR 3 MILES,BUT ≥ 400 FEET AND 1 MILE   CAT1 ILS=FREQ(4)/FREQ(2)

(4) < 400 FEET AND/OR 1 MILE, BUT > 200 FEET AND 1/2 MILE   CAT2 ILS=FREQ(5)/FREQ(2)

(5) < 200 FEET AND/OR 1/2 MILE,BUT ≥100 FEET AND 1/4 MILE   *BELOW MINIMUMS=FREQ(6)/FREQ(2)

(6) < 100 FEET AND/OR 1/4 MILE

To determine the increased IFR runway utilization to be
expected with a new approach-and-landing aid, divide the
percentage of instrument weather (defined herein as equal
to or less than 1,500-feet ceiling and/or 3 miles visibility)

in the category given by the new navaid by the percentage given by the old aid. In the example on the previous page, 11.5 percent (10.0 plus 1.5) of all observations were instrument approach weather better than Category I minimums (200-½) while 10.0 percent of the observations were better than VOR minimums (400-1). Therefore, if an ILS reduced minimums from 400-1 to 200-½, one would expect an increase of 15 percent (11.5/10.0 = 115%) in runway utilization during instrument weather conditions and a corresponding decrease in flight disruptions (delays, diversions, and cancellations).

Data for the 271 airports can be used directly if the weather categories of interest coincide with those published. If not, estimates can be interpolated from this and other weather data or actual data can be obtained from the basic detail information for each airport stored on magnetic tape. For those airports not on the list of 271, use the nearest airport for which data is available and at which weather patterns are similar.

To assist in interpolating for other than published weather categories, national averages of weather equal to or less than minimums of from 200-½ through 1500-3 are given in Table C-1. This data is based on averages of percentage distributions of hourly ceiling and visibility observations at 32 airports, representing in most cases 10 years of data from 1949 through 1958 (Reference 14).

TABLE C-1

Percentage Distributions of Weather Observations
Equal to or Less Than Selected Ceilings and/or Visibilities

Ceiling (Feet)	Visibility (Miles)				
	1/2	3/4	1	1-1/2	3
	%	%	%	%	%
200	1.12	1.52	2.01	3.13	7.10
300	1.48	1.79	2.21	3.25	7.13
400	2.14	2.37	2.73	3.64	7.29
500	2.88	3.08	3.38	4.20	7.60
600	3.67	3.84	4.09	4.81	7.99
700	4.57	4.72	4.95	5.60	8.57
800	5.47	5.61	5.81	6.40	9.15
1,000	7.24	7.36	7.54	8.05	10.48
1,500	10.80	10.91	11.05	11.45	13.48

In Table C-2, the data in Table C-1 is expressed as differences between 1500-3, usually the minimums below which instrument approaches are counted, and specified minimums. For example, on the average 13.48 percent of all weather observations are less than 1,500 feet ceiling and/or 3 miles visibility. For a nonprecision approach with minimums of 400-1, 2.73 percent of all observations, on the average, are equal to or less than 400 feet ceiling and/or 1 mile visibility. The difference between the two--13.48 minus 2.73 = 10.75--is the percentage of weather observations falling between minimums of 1500-3 and 400-1.

TABLE C-2

Percentage Distributions of Weather Observations
between Specified Minimums and 1500-3

Ceiling (Feet)	Visibility (Miles)				
	1/2	3/4	1	1-1/2	3
	%	%	%	%	%
200	12.36	11.96	11.47	10.35	6.38
300	12.00	11.69	11.27	10.23	6.35
400	11.34	11.11	10.75	9.84	6.19
500	10.60	10.40	10.10	9.28	5.88
600	9.81	9.64	9.39	8.67	5.49
700	8.91	8.76	8.53	7.88	4.91
800	8.01	7.87	7.67	7.08	4.33
1,000	6.24	6.12	5.94	5.43	3.00
1,500	2.68	2.57	2.43	2.03	0

Table C-3 gives the average increases in airport utilization associated with reductions from specified nonprecision approach minimums to ILS minimums (200-1). For example, from Table C-2 we find that 12.36 percent of all weather observations lie between 1500-3 and 200-½, and 10.75 percent lie between 1500-3 and 400-1. If an ILS permitted a reduction in minimums of from 400-1 to 200-½, we would expect an average 15 percent increase in runway utilization (12.36/10.75 = 115%). Similarly, if minimums were reduced from 800-1½ to 400-1, we would expect a 52 percent increase in runway utilization (10.75/7.08 = 1.52). In this way, the increased runway utilization associated with any change in approach minimums can be estimated.

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TABLE C-3

Average Increases in Airport Utilization
Associated with Reductions in Approach Minimums
from Specified Values to ILS Minimums
(200 feet and/or ½ mile)

Ceiling (Feet)	Visibility (Miles)				
	1/2	3/4	1	1-1/2	3
	%	%	%	%	%
200	0	3.3	7.8	19.5	93.7
300	3.0	5.7	9.7	20.9	94.5
400	9.0	11.3	15.0	25.6	99.9
500	16.6	18.9	22.4	33.2	110.4
600	25.9	28.2	31.7	42.6	125.0
700	38.7	41.1	44.9	56.9	151.7
800	54.1	56.9	61.1	74.6	185.3
1,000	97.9	102.0	108.0	127.4	312.3
1,500	360.5	379.9	407.2	507.7	-

The data in Tables C-1 through C-3 is based on national averages. Weather patterns at individual airports may differ significantly from these averages, but the data in the above tables nevertheless is useful in interpolating between values published in the 271 airport weather report. For example, Sioux Falls, South Dakota, is a candidate for an ILS on Runway 21. That runway now has a localizer back course approach with minimums of 400-3/4. We saw in the tabulation on Page C-1 that at Sioux Falls a reduction in minimums of from 400-1 to 200-½ would increase airport utilization during instrument weather conditions by 11.5/10.0 = 1.15, or by 15 percent. No data is given for minimums of 400-3/4. Referring to Table C-3, however, we see that if lowering minimums 400-1 to 200-½ increases IFR airport utilization by 15.0 percent, a reduction from 400-3/4 to 200-½ can be expected to give an increase of 11.3 percent. In a similar manner, or by proportioning observed to average values, one can determine the expected increase in runway utilization associated with any reduction in minimums.

INDEX OF 271 AIRPORTS FOR WHICH WEATHER DATA IS AVAILABLE

	Location	Airport	Lat. (N)	Long. (W)	Elev. (Ft.)	Page
	ALABAMA					
	Birmingham	Municipal	33:34	86:45	630	1
	Dothan	Dothan	31:14	85:26	325	1
1)	Huntsville	Municipal	34:42	86:35	606	2
	Mobile	Bates	30:41	88:15	221	2
	Montgomery	Dannelly	32:18	86:24	202	3
	Muscle Shoals	Muscle Shoals	34:45	87:37	562	3
	Tuscaloosa	Van de Graaff	33:14	87:37	186	4
	ALASKA					
	Anchorage	International	61:10	149:59	132	4
	Anchorage	Merrill	61:13	149:50	132	5
	Fairbanks	International	64:49	147:52	454	5
	Juneau	Municipal	58:22	134:35	24	6
	Kenai	Municipal	60:34	151:16	91	6
	King Salmon	King Salmon	58:41	156:39	49	7
	Kodiak	Municipal	57:44	152:31	112	7
	ARIZONA					
	Phoenix	Sky Harbor	33:26	112:01	1112	8
	Tucson	International	32:07	110:56	2558	8
	ARKANSAS					
	Fort Smith	Municipal	35:20	94:22	463	9
	Little Rock	Adams Field	34:44	92:14	265	9
	Texarkana	Webb Field	33:27	94:00	368	10
	CALIFORNIA					
	Arcata		40:59	124:06	225	10
	Bakersfield	Kern County	35:25	119:03	497	11
	Burbank	Hollywood-Burbank	34:12	118:22	775	11
	Chula Vista	Brown Field	32:24	116:58	525	12
	Fresno	Air Terminal	36:46	119:43	330	12
	Long Beach	Daugherty	33:49	118:09	40	13
	Los Angeles	International	33:56	118:24	104	13
	Monterey	NAF	36:35	121:52	164	14
	Oakland	Metropolitan	37:44	122:12	7	14
	Ontario	International	34:03	117:37	934	15
	Sacramento	Executive	38:31	121:30	25	15
	Salinas	Municipal	36:40	121:36	78	16
	San Diego	Lindbergh Field	32:44	117:10	28	16
	San Francisco	International	37:37	122:23	18	17
	San Jose	Municipal	37:22	121:55	56	17
	Santa Ana	Orange County	33:40	117:53	53	18
	Santa Barbara	Municipal	34:26	119:50	20	18
	Stockton	Metropolitan	37:54	121:15	27	19

Location	Airport	Lat. (N)	Long. (W)	Elev. (Ft.)	Page
COLORADO					
Colorado Springs	Peterson Field	38:49	104:42	6170	19
Denver	Stapleton Int'l.	39:45	104:52	5332	20
Grand Junction	Municipal	39:06	108:32	4839	20
Pueblo	Memorial	38:17	104:31	4639	21
CONNECTICUT					
Bridgeport	Municipal	41:10	73:08	25	21
Hartford	Bradley Int'l.	41:56	72:41	179	22
DELAWARE					
Wilmington	Greater	39:40	75:36	80	22
FLORIDA					
Daytona Beach	Regional	29:11	81:03	61	23
2) Fort Lauderdale	Fort Lauderdale-Hollywood Int'l.	26:04	80:09	8	23
Fort Myers	Page Field	26:34	81:52	20	24
3) Jacksonville	Imeson	30:30	81:42	31	24
Melbourne	Cape Kennedy Regional	28:06	80:38	28	25
Miami	International	25:48	80:16	12	25
Orlando	Herndon	28:33	81:20	119	26
2) Panama City	Bay County	30:12	85:41	20	26
Pensacola	Regional	30:28	87:12	118	27
2) Sarasota	Sarasota-Bradenton	27:24	82:33	24	27
Tallahassee	Dale Mabry	30:26	84:20	68	28
Tampa	International	27:58	82:32	11	28
West Palm Beach	International	26:41	80:06	21	29
GEORGIA					
Athens	Clarke County	33:57	83:19	801	29
Albany	Dougherty County	31:32	84:11	193	30
Atlanta	Hartsfield Int'l.	33:39	84:26	1034	30
Augusta	Bush	33:22	81:58	148	31
Columbus	Metropolitan	32:31	84:56	389	31
Macon	Lewis B. Wilson	32:42	83:39	362	32
Savannah	Travis Field	32:08	81:12	51	32
Valdosta	Municipal	30:47	83:17	216	33
HAWAII					
Hilo	Lyman Field	19:43	155:04	36	33
Honolulu	International	21:20	157:55	15	34
Kahului	Kahului	20:54	156:26	67	34
Lihue	Lihue	21:59	159:21	148	35

Location	Airport	Lat. (N)	Long. (W)	Elev. (Ft.)	Page
IDAHO					
Boise	Municipal	43:34	116:13	2868	35
Idaho Falls	Fanning Field	43:31	112:04	4744	36
Pocatello	Municipal	42:55	112:36	4454	36
ILLINOIS					
2) Champaign	Univ. of Illinois-Willard	40:02	88:17	777	37
Chicago	Midway	41:47	87:45	623	37
Chicago	O'Hare	41:59	87:54	674	38
Moline	Quad City	41:27	90:31	594	38
Peoria	Greater	40:40	89:41	662	39
Rockford	Greater	42:12	89:06	743	39
Springfield	Capital	39:50	89:40	613	40
INDIANA					
Evansville	Dress Regional	38:03	87:32	388	40
Fort Wayne	Baer Field	41:00	85:12	828	41
Indianapolis	Weir Cook	39:44	86:17	808	41
South Bend	St. Joseph County	41:42	86:19	773	42
Terre Haute	Hulman	39:27	87:18	593	42
West Lafayette	Purdue University	40:25	86:56	637	43
IOWA					
2) Cedar Rapids	Municipal	41:53	91:42	901	43
Des Moines	Municipal	41:32	93:39	963	44
Waterloo	Municipal	42:33	92:24	878	44
Sioux City	Municipal	42:24	96:23	1103	45
KANSAS					
Hutchinson	Hutchinson	38:04	97:52	1524	45
2) Salina	Salina	38:49	97:34	1275	46
Topeka	Municipal	39:04	95:38	885	46
Wichita	Municipal	37:39	97:25	1340	47
KENTUCKY					
Covington	(See Cincinnati)				
Lexington	Blue Grass	38:02	84:36	989	47
London	Corbin-London	37:05	84:05	1189	48
Louisville	Standiford	38:11	85:44	488	48
LOUISIANA					
Alexandria	Esler	31:23	92:18	118	49
Baton Rouge	Ryan	30:32	91:09	76	49
Lafayette	Municipal	30:12	91:59	42	50
Lake Charles	Municipal	30:07	93:13	14	50
Monroe	Municipal	32:31	92:03	81	51
New Orleans	Moisant	29:59	90:15	30	51
Shreveport	Regional	32:28	93:49	259	52

Location	Airport	Lat. (N)	Long. (W)	Elev. (Ft.)	Page
MAINE					
Augusta	State	44:19	69:48	360	52
Bangor	International	44:48	68:49	192	53
Portland	Int'l. Jetport	43:39	70:19	63	53
MARYLAND					
Baltimore	Friendship	39:11	76:40	155	54
Hagerstown	Municipal	39:42	77:43	704	54
Salisbury	Wicomico County	38:20	75:30	60	55
MASSACHUSETTS					
Bedford	Hanscom	42:28	71:17	143	55
Boston	Logan	42:22	71:02	29	56
Nantucket	Memorial	41:15	70:04	12	56
2) Westfield	Barnes	42:09	72:43	263	57
Worcester	Municipal	42:16	71:52	986	57
MICHIGAN					
Battle Creek	Kellogg	42:18	85:14	939	58
Detroit	City	42:25	83:01	626	58
Detroit	Metropolitan	42:14	83:20	664	59
Detroit	Willow Run	42:14	83:32	777	59
Flint	Bishop	42:58	83:44	766	60
Grand Rapids	Kent County	42:54	85:40	689	60
Jackson	Reynolds	42:16	84:28	1020	61
2) Kalamazoo	Municipal	42:17	85:36	955	61
Lansing	Capital City	42:47	84:36	874	62
Muskegon	County	43:10	86:14	633	62
Saginaw	Tri-City	43:26	83:52	601	63
Traverse City	Cherry Capital	44:44	85:35	630	63
MINNESOTA					
Duluth	International	46:50	92:11	1417	64
Minneapolis	Minn.-St. Paul	44:53	93:13	838	64
Rochester	Municipal	43:55	92:30	1297	65
St. Paul	Holman Field (Downtown)	44:56	93:04	720	65
MISSISSIPPI					
4) Jackson	Municipal	32:20	90:13	332	66
Meridian	Key Field	32:20	88:45	310	66
MISSOURI					
5) Kansas City	Municipal	39:07	94:36	750	67
Springfield	Municipal	37:14	93:23	1270	67
St. Joseph	Rosecrans Memorial	39:46	94:55	818	68
St. Louis	Lambert	38:45	90:23	544	68

Location	Airport	Lat. (N)	Long. (W)	Elev. (Ft.)	Page
MONTANA					
Billings	Logan Field	45:48	108:32	3570	69
Great Falls	International	47:29	111:22	3657	69
Helena	Municipal	46:36	112:00	3898	70
Missoula	Johnson-Bell Field	46:55	114:05	3189	70
NEBRASKA					
Lincoln	Municipal	40:51	96:46	1169	71
Omaha	Eppley	41:18	95:54	982	71
NEVADA					
Las Vegas	McCarran Int'l.	36:05	115:10	2162	72
Reno	International	39:30	119:47	4400	72
NEW JERSEY					
Atlantic City	NAFEC-Pomona	39:27	74:34	67	73
Newark	International	40:42	74:10	30	73
Teterboro	Teterboro	40:51	74:03	7	74
NEW MEXICO					
Albuquerque	International	35:03	106:37	5314	74
Farmington	Farmington	36:45	108:15	5509	75
Hobbs	Lea County	32:41	103:12	3664	75
Roswell	Air Center	33:18	104:32	3649	76
NEW YORK					
Albany	County	42:45	73:48	292	76
Binghamton	Broome County	42:13	75:59	1629	77
Buffalo	Greater	42:56	78:44	706	77
Elmira	Chemung County	42:10	76:54	954	78
Glen Falls	Warren County	43:20	73:37	71	78
2) Islip	MacArthur	40:47	73:06	98	79
New York	J. F. Kennedy	40:39	73:47	22	79
New York	LaGuardia	40:46	73:54	31	80
Niagara Falls	Municipal	43:06	78:57	625	80
Poughkeepsie	Dutchess County	41:38	73:53	162	81
Rochester	Rochester-Monroe County	43:07	77:40	555	81
Syracuse	Hancock	43:07	76:07	408	82
2) Utica	Oneida County-Oriskany	43:09	75:23	731	82
White Plains	Westchester County	41:04	73:43	443	83

Location	Airport	Lat. (N)	Long. (W)	Elev. (Ft.)	Page
NORTH CAROLINA					
8) Asheville	Asheville	35:26	82:32	2140	83
Charlotte	Douglas	35:13	80:56	769	84
2) Fayetteville	Grannis	35:00	78:53	189	84
Greensboro	Greensboro-High Point	36:05	79:57	886	85
Raleigh	Raleigh-Durham	35:52	78:47	441	85
Wilmington	New Hanover County	34:16	77:55	38	86
Winston-Salem	Smith-Reynolds	36:07	80:12	995	86
NORTH DAKOTA					
Bismarck	Municipal	46:46	100:45	1660	87
Fargo	Hector	46:54	96:48	899	87
Grand Forks	International	47:55	97:05	832	88
OHIO					
Akron	Akron-Canton	40:55	81:26	1236	88
Cincinnati	Greater	39:04	84:40	877	89
Cleveland	Hopkins Int'l.	41:24	81:51	805	89
Columbus	Port Columbus	40:00	82:53	833	90
Dayton	J. M. Cox	39:54	84:13	1003	90
Mansfield	Lahm Municipal	40:49	82:31	1301	91
Toledo	Express	41:36	83:48	692	91
Youngstown	Municipal	41:16	80:40	1186	92
OKLAHOMA					
2) Lawton	Municipal	34:34	98:25	1108	92
Oklahoma City	Will Rogers	35:24	97:36	1304	93
Tulsa	International	36:12	95:54	676	93
OREGON					
Eugene	Mahlon Sweet Field	44:07	123:13	373	94
Klamath Falls	Kingsley	42:09	121:44	4102	94
Medford	Jackson County	42:22	122:52	1329	95
North Bend	Municipal	43:25	124:15	17	95
Pendleton	Pendleton Field	45:41	118:51	1482	96
Portland	International	45:36	122:36	39	96
Salem	McNary Field	44:55	123:00	209	97
PENNSLYVANIA					
Allentown	Allentown-Bethlehem-Easton	40:39	75:26	385	97
Bradford	Regional	41:48	78:38	2150	98
Erie	International	42:05	80:05	737	98
Franklin	Chess Lamberton	41:23	79:52	1540	99
Harrisburg	Harrisburg State	40:13	76:51	351	99
Middletown	Olmsted Field	40:12	76:46	318	100
Philadelphia	International	39:53	75:15	28	100
Philadelphia	North	40:05	75:01	119	101

Location	Airport	Lat. (N)	Long. (W)	Elev. (Ft.)	Page
Pittsburgh	Allegheny County	40:21	79:56	1273	101
Pittsburgh	Greater	40:30	80:13	1225	102
Wilkes-Barre	Wilkes-Barre-Scranton	41:20	75:44	948	102
Williamsport	Lycoming County	41:15	76:55	525	103

PUERTO RICO

San Juan	Isle Verde	18:26	66:00	62	103

RHODE ISLAND

Providence	T. F. Green	41:44	71:26	62	104

SOUTH CAROLINA

Charleston	Municipal	32:54	80:02	48	104
Columbia	Metropolitan	33:57	81:07	225	105
6) Greenville	Municipal	34:51	82:21	1023	105
Florence	Municipal	34:11	79:43	148	106
Myrtle Beach	South	33:41	78:56	25	106

SOUTH DAKOTA

Rapid City	Municipal	44:02	103:03	3168	107
Sioux Falls	Foss Field	43:34	96:44	1427	107

TENNESSEE

Bristol	Tri City	36:29	82:24	1566	108
Chattanooga	Lovell	35:02	85:12	688	108
Knoxville	Municipal	35:49	82:24	980	109
Memphis	International	35:03	89:59	284	109
Nashville	Metropolitan	36:07	86:41	605	110

TEXAS

Abilene	Municipal	32:27	99:41	1790	110
Amarillo	Air Terminal	35:14	101:42	3604	111
Austin	Mueller	30:18	97:42	621	111
Brownsville	International	25:55	97:28	20	112
7) Corpus Christi	Cliff Maus	27:46	97:26	44	112
Dallas	Love Field	32:51	96:51	488	113
El Paso	International	31:48	106:24	3916	113
Fort Worth	Greater Southwest	32:50	97:03	576	114
Galveston	Scholes Field	29:16	94:51	9	114
8) Houston	Intercontinental	29:58	95:21	96	115
Houston	International	29:39	95:17	50	115
Laredo	Municipal	27:32	99:29	512	116

Location	Airport	Lat. (N)	Long. (W)	Elev. (Ft.)	Page
Longview	Gregg County	32:23	94:43	373	116
Lubbock	Regional	33:39	101:50	3242	117
Midland	Midland-Odessa	31:56	102:12	2858	117
Port Arthur	Jefferson County	29:57	94:01	22	118
San Angelo	Mathis Field	31:22	100:30	1908	118
San Antonio	International	29:32	98:28	794	119
Tyler	Pounds Field	32:21	95:24	551	119
Waco	Municipal	31:37	97:13	508	120

UTAH

Location	Airport	Lat. (N)	Long. (W)	Elev. (Ft.)	Page
Ogden	Ogden	41:12	112:01	4446	120
Salt Lake City	International	40:46	111:58	4227	121

VERMONT

Location	Airport	Lat. (N)	Long. (W)	Elev. (Ft.)	Page
Burlington	International	44:28	73:09	340	121

VIRGINIA

Location	Airport	Lat. (N)	Long. (W)	Elev. (Ft.)	Page
2) Charlottesville	Charlottesville-Albemarle	38:08	78:27	644	122
Lynchburg	Municipal	37:20	79:12	937	122
Norfolk	Norfolk Regional	36:54	76:12	30	123
Pulaski	New River Valley	37:05	80:47	2105	123
Richmond	R. E. Byrd	37:30	77:20	177	124
Roanoke	Municipal	37:19	79:58	1176	124
Washington, DC	Andrews	38:49	76:51	274	125
Washington, DC	Dulles	38:57	77:27	323	125
Washington, DC	National	38:51	77:02	65	126

VIRGIN ISLANDS

Location	Airport	Lat. (N)	Long. (W)	Elev. (Ft.)	Page
St. Croix	Alex Hamilton	17:42	64:48	55	126
St. Thomas	H. S. Truman	18:20	64:58	15	127

WASHINGTON

Location	Airport	Lat. (N)	Long. (W)	Elev. (Ft.)	Page
Everett	Paine Field	47:55	122:17	613	127
Moses Lake	Grant	47:11	119:19	1182	128
Olympia	Municipal	46:58	122:53	215	128
Seattle	Boeing Field	47:32	122:18	30	129
Seattle	Seattle-Tacoma	47:27	122:18	450	129
Spokane	International	47:38	117:32	2365	130
Yakima	Air Terminal	46:34	120:32	1066	130

WEST VIRGINIA

Location	Airport	Lat. (N)	Long. (W)	Elev. (Ft.)	Page
Beckley	Raleigh County	37:47	81:07	2514	131
Charleston	Kanawha	38:22	81:36	951	131
8) Huntington	Tri-State	38:22	82:33	828	132
Parkersburg	Wood County	39:21	81:26	864	132

Location	Airport	Lat. (N)	Long. (W)	Elev. (Ft.)	Page
WISCONSIN					
Green Bay	Austin Straubel	44:29	88•08	702	133
La Crosse	Municipal	43:52	91:15	663	133
Madison	Truax Field	43:08	89:20	866	134
Milwaukee	Mitchell Field	42:57	87:54	693	134
2) Oshkosh	Wittman	44:00	88:34	785	135
WYOMING					
Casper	Air Terminal	42:55	106:28	5290	135
Cheyenne	Municipal	41:09	104:49	6144	136

1) Insufficient digitized weather data from Huntsville-Madison County Airport.

2) Hours 0700-2100 LST only are summarized.

3) Insufficient digitized weather data from International Airport.

4) Insufficient digitized weather data from Thompson Field.

5) Insufficient digitized weather data from International Airport.

6) Insufficient digitized weather data from Greenville-Spartanburg Airport.

7) Insufficient digitized weather data from International Airport.

8) Summary is based on eight 3-hourly observations per day.